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Bachelor Thesis

“DEMAND-SIDE MANAGEMENT. KEY TO DECARBONIZATION”

Irene Antón Sierra

Fernando Soto Martos

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ABSTRACT

Decarbonization is one of the biggest challenges of our time. The European Union, as other organizations have already designed the strategies to achieve a more sustainable future. The integration of renewable energy sources is not a technical challenge anymore.

However, due to the variability of these type of technologies some actions should be implemented so the conventional ones are not needed any more. One crucial solution is the implementation of demand side management actions which focus on controlling the demand rather than the generation.

This thesis identifies the different actions on different demand side management actions and their performance in Spain. Also, an analysis regarding implemented policies in other European countries is performed to identify successful actions that could be later implemented in Spain.

Keywords: Demand side management, decarbonization, aggregation, electric vehicles, self- consumption.

DEDICATION

To my tutor, my family and everyone who have helped me inside and outside of university in the elaboration of this thesis and in my journey through the degree these last four years.

Para mi tutor, my familia y toda la gente que me ha ayudado de dentro y fuera de la universidad en la elaboración de este TFG y en mi camino a través de la carrera estos últimos cuatro años.

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1. INTRODUCTION

In this chapter there is an introduction to the thesis. A contextualization of the situation has been made to understand the importance of decarbonization and why more actions should be adopted.

1.1. Background and motivation

During these four years studying energy related topics, decarbonization and the need of a change in the electric system to achieve a more sustainable development have been recurrent and concerning challenges.

My personal interest in this topic comes especially from one of the subjects of the fourth year of the degree, “Energy demand management and risk management in non-financial companies”. I have had a genuine interest in decarbonization and in the modification of the energy system to make it more sustainable from the beginning of my studies and that subject introduced me to a possible enabler of this transition that does not only encounter technical challenges; that is demand side management.

Changing the electric system as we know it will be one of the main focus of the sector in the following years, and so I will most likely be working in some of the technologies that are gathered in this thesis. For this reason, the thesis will help me have a clear overview of the operation of the system now, the actions that are already implemented and those that will be in the following years. Similarly, having some knowledge about how Spain is doing regarding demand side management compared to other European countries will help me identify the areas that are yet to be developed and in which I could play a role as a professional.

1.2. Socio-economic and environmental framework

Energy is the oxygen of the world as we know it. All societies need sustainable, secure, safe and affordable energy to keep running and developing.

In the last decades, there has been an increase of awareness about the energetic crisis that the world has somehow already started to face. Climate change and the greenhouse emissions that produce it are now concerns of all western governments and organizations. Also, many countries are experimenting a rise of energy demand which increases the risk of supply disruptions, and unstable prices.

Decarbonization could be a possible solution to this energetic crisis and ideal future. Although changing the whole energy system into a sustainable and secure one will still take many years, the actions and regulations that are been set now can start the way to a decarbonized future. There are many aspects that should be considered when planning a decarbonized world besides energy generation, such as heating, cooling, and transportation but certainly the control of the sources of energy generation will be key to decarbonization.

One of these actions is the integration of renewables sources of energy into the generation mix, which does not suppose a technical challenge anymore. However, the difficulty to forecast their performance makes it impossible to have a reliable system that it is only composed of renewables. So, since the ideal future supply would be unpredictable, the only possible way to guarantee that the supply meets the demand at all times and that the risk of supply disruption is rather small would be having control over the demand. As we cannot totally control all the energy consumption of the population, the only way of adding flexibility to the demand is adding actions that help providing a system where consumption can be more efficient without having to change drastically the habits of the end consumer. [1]

A more flexible demand for electricity will provide good conditions for the increase of the share of renewables into the generation mix, and so, decrease the dependency on fossil fuels and reduce the greenhouse emissions.

Demand side management is composed by the set of actions that can be taken in order to get a more flexible demand. It focuses on reducing consumption and decreasing the difference between the peak and the off-peak in the demand curve. The total introduction of the smart meters and the future smart grid opens new possibilities for demand side management. The implementation of these actions will make it easier for the integration of renewables as it will help to compensate the variability associated with their generation. However, the energy sector is a regulated market, and so, governments and their policies would be the ones setting the pace of the progress to a flexible demand (and so, help decarbonization) instead of technological advances alone.

Some of the policies regarding demand side management have been enforced for quite some time as interrumpibility while others have been changing in the last years as self-consumption. The latest changes are gathered in the Royal Decrees of October 2018 and April 2019.

1.3. Objectives of the thesis

The objectives of the thesis are:

• Study the function of demand side management to achieve decarbonization. Study how can demand side management help changing the actual energy system into another in which the renewable share of the generation mix is greater, reducing the use of carbon and its impact.

• Identify policies and actions regarding demand side management of Spain, Germany, France and the Netherlands. Gather different actions that help to have a flexible demand as aggregation, the introduction of the electric vehicle and self-consumption in Spain, Germany, France and the Netherlands will be discussed. The aim is to study what is the impact they have into the energy system and how each of them can help providing a more viable scenario for decarbonization.

• Analyze and compare the demand side management policies in Spain, Germany, France and the Netherlands to suggest possible recommendations of future policies. Analyze the level of implementation of each action in each country to identify those leading in each type so these policies could be taken as a reference for other countries.

To meet these targets the knowledge acquired along the degree will be used, specially that provided by subjects as “Demand side management and risk management for non-financial companies” and “Regulation of electricity markets”.

1.4. Structure

This thesis will first give an overall perspective in the goals that the European Union has set and check how much are the countries on track in order to meet them, and in the characteristics and regulations of the Spanish electric market. The knowledge about the degree of achievement of the goals will be helpful to identify the need of demand side management actions. Then, a brief study on the Spanish demand will be addressed.

Afterwards, a discussion of some of the actions of demand side management and their state in the Spanish system will follow. The aim then is to compare the system in Germany, France and the United Kingdom and their differences in the regulation of the different demand side management actions. Finally, taking the comparison into account, new actions that Spain could take in order to be on track to meet the goals of the European Union would be discussed as well as possible business opportunities that appear with the implementation of new demand side management actions.

So, the distribution used to meet the targets previously described is the following:

-Chapter 1: Background, objectives and methodology of the thesis.

-Chapter 2: Explanation of the European Union targets to meet decarbonization and analysis of the performance thus far.

-Chapter 3: General operation review of the Spanish electric system.

-Chapter 4: Description of the characteristics of electricity demand and the factors that affect it.

-Chapter 5: Definition of demand side management, classification of challenges and description of types.

-Chapter 6: Identification of the regulatory framework for the implemented demand side management actions in Spain.

-Chapter 7: Collection of characteristics of electric systems, demand side management actions and regulatory framework of Germany, France and the Netherlands.

-Chapter 8: Comparison of the demand side management actions in Spain, France, Germany and the Netherlands and analysis of the degree of implementation of each of them.

-Chapter 9: Recommendations about future demand side management policies based on the analysis of chapter 8.

-Chapter 10: Collection of business opportunities that arise from the implementation of demand side management actions.

-Chapter 11 and Chapter 12: Gantt diagram and budget of the thesis.

Chapter 13: Technical and personal conclusions obtained from the elaboration of the thesis.

1.5. Resources used

For the elaboration of the thesis a vast collection of bibliography has been consulted, from the European Union databases to royal decrees and the official data and reports published by the TSOs of the different countries analyzed. All the bibliography is gathered in chapter 14.

Regarding the computer programs used to elaborate the thesis, the document has been written in Microsoft Word, and then edited into LaTeX. A basic course on the LaTeX language was needed to do so. Also, the graphs have been elaborated in Excel, extracting the data from the different online data bases.

2. EUROPEAN UNION STRATEGIES.

In 2011, the European Commission's Energy roadmap set the routes for a future sustainable, secure and competitive energy system and combined them to get different possible scenarios for 2050 [2]. After analyzing them, some of the conclusions are that decarbonization is possible, from both technological an economical approach. A reduction in greenhouse emissions now will make the price of electricity lower in the future. Also, increasing the renewable share is crucial for achieving decarbonization. For these reasons, the analysis concludes that changing the infrastructure for low-carbon alternatives will be more profitable now than in the future. Finally, in order to be more efficient, the analysis suggests that promoting a common european energy market will make the energy cheaper, and the market more secure and efficient.

Following the roadmap proposed in 2011, several short, medium and long-term goals related to climate change and energy usage aiming to reduce gas emissions, increase energy savings and the share of renewable energy in the generation mix. Through the compliance of the goals and a new energy strategy, the EU will help combat the climate change while providing a sustainable and competitive energy system.

The target values for each of the goals give a general view about the progress that Europe should have reached by the milestones in order to be on track for a more efficient and decarbonized future. The goals are set relating to European Union values, so they will be achieved as the sum of the different countries values reaches the designated objectives. However, in order to ease each country fulfillment, the Europe strategies are used as a reference to establish different national targets. Each nation will regulate to achieve their own goals and will be able to check their own progress.

These european strategies aim for a decarbonized economy in 2050, and for that, it has set the different goals and milestones that will be described. However, the decarbonized economy must be achieved worldwide. Not only Europe should decrease its greenhouse emissions and increase their renewable energy generation. The actions that the European Union takes are important to achieve the ultimate goal of decarbonization, but the global tendency should be similar to the goals to truly achieve it.

2.1. Europe 2020

The Europe 2020 strategy was established in 2010 by the European Commission. Its main targets are to increase the share of renewable energy of the energy mix by at least 20%, reduce the greenhouse emissions by at least 20% compared to 1990 data and to increase the energy savings by at least 20%. In the case of energy savings, the target values are collected in Article 3 of Directive 2012/27/EU. It states that the european consumption of primary energy should be less than 1474 Mtoe (Million Tonnes of equivalent oil), or the final energy consumption should be lower than 1078 Mtoe. They are calculated taking 2005 data as a reference and the projections for energy consumption in 2020. [3]

Spain's targets

The Spanish targets are exposed at the Renewable Energy Plan 2011-2020 approved on November 2011 by the Cabinet of Ministers. [4] The consumption of energy generated with renewables should account for 20.8%. Also, the plan includes a target for the electricity demand that is met by renewable resources, it should be 39%. [2]

Also, Spain has set some goals regarding the greenhouse emissions that are collected in the Kyoto Protocol. On one side there is a common European goal regarding the industries that do an intensive use of energy such as generation, to decrease the greenhouse emissions by 21% compared to 2005 data. The other goal regarding the greenhouse emissions is set for the commercial sectors, and following the Decision 406/2009/CE, Spain should make a reduction of 10% compared to 2005 data. [5]

Finally, the goal intended to increase the energy savings was not distributed among all the country members in other specific goals for each country, so there is not a different goal for Spain. The target is also to increase energy efficiency by 20% as the rest of the countries. In the case of Spain, a 20% increase in energy efficiency means that the primary consumption of energy should be lower than 119.8 Mtoe.

	EUROPE 2020	SPAIN 2020
Share of renewable energy	at least 20 %	at least 20.8%
Greenhouse emissions reduction	at least 20% (1990 data)	at least 21% (intensive energy use industry) (2005 data)
		at least 10% (commercial energy use) (2005 data)
Energy savings	at least 20 % (1483 Mtoe of primary energy consumption)	at least 20% (119.8 Mtoe of primary energy consumption)

Table 2.1. - Europe and Spain targets for renewable energy, greenhouse gases and energy efficiency [6]

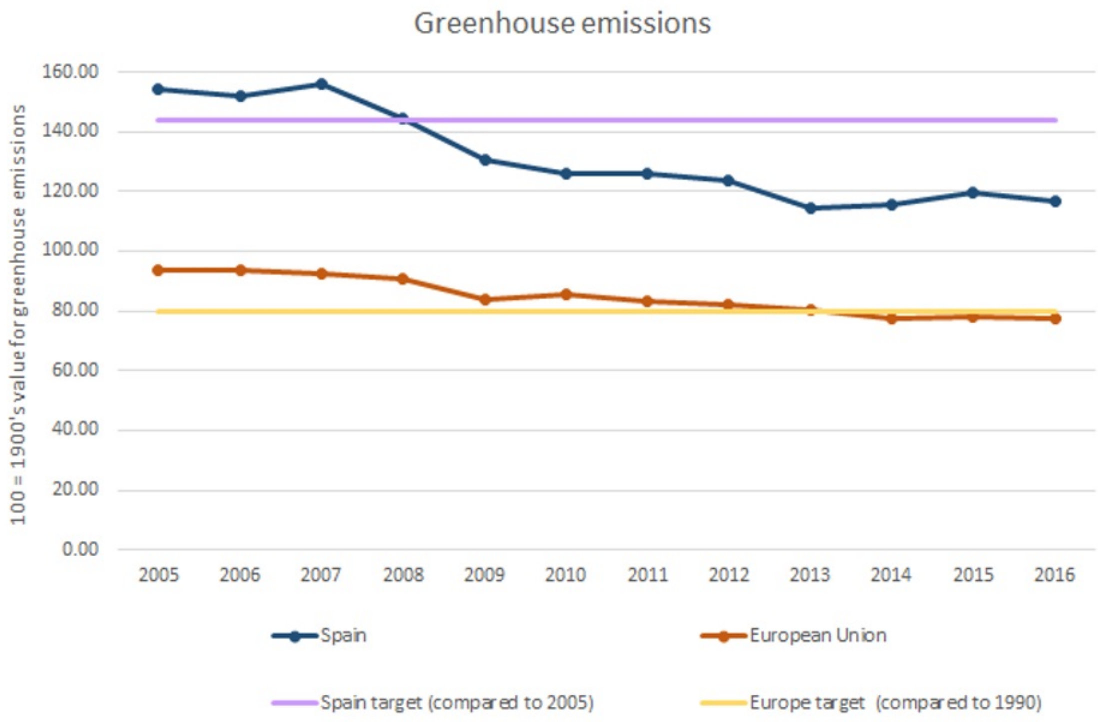
In comparison, almost all the Spanish goals are of the same range than those of Europe. However, the year to take data to compare varies significantly from 1990 for the European Union and 2005 for Spain. The effect of this base difference will be discussed in the following sections.

2.1.1. Achievement

In this section we will analyze how far Spain and the European Union are from reaching the targets mentioned above.

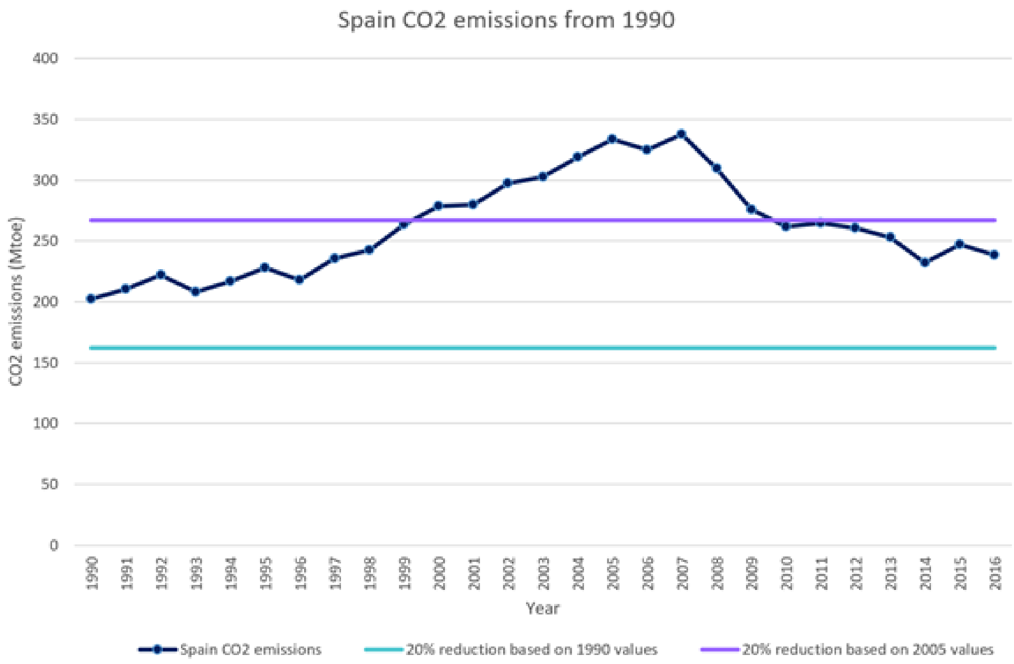
Greenhouse emissions

In the case of the greenhouse emissions target, Spain had already achieved the 2020 goal regarding the industrial sectors by 2009. Also, the European Union goal was already achieved by 2016, where the 22.36% of reduction was achieved.



Graph 2.1. - Europe and Spain greenhouse emissions evolution and targets [57]

However, it should be noticed that the goal set by Spain has different reference values that the one for Europe and this difference is very significant. The reference values of Spain correspond to 2005, which are higher than those of 1990, in part due to the economic recession that the country was experiencing at that time. Since the reference values are much higher in 2005, the achievement of the national goal has been easier. This is the evolution of the emissions in Spain since 1990.

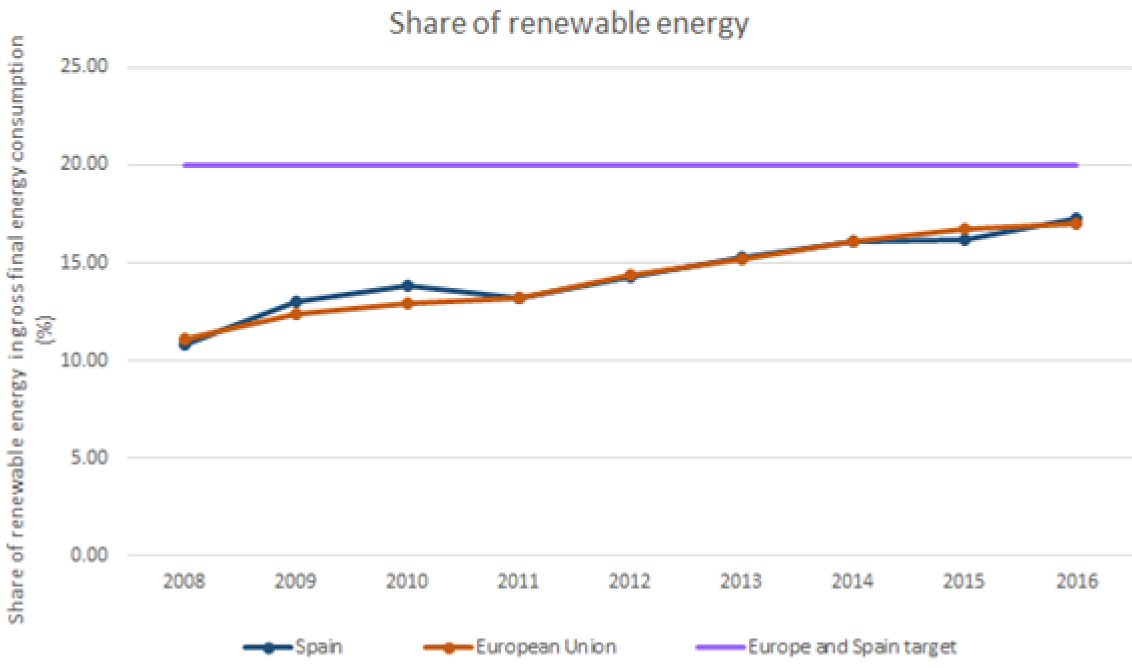


Graph 2.2. - Spain emissions and targets evolution [7]

The current goal for Spain states that the value for 2020 should be 266.97 Mtoe, taking into account the reduction compared to 2005 values. However, as seen in the graph, if the target was to be compared with 1990 values just as the one set for the European Union, it should be 162.1 Mtoe, a little over 100 Mtoe less than the current target.

Share of renewable energy

The share of renewable energy was quite similar between Spain and the European Union in 2016. Spain only had 0.3% more of renewable energy into the generation mix. Both cases are approximately 3% away of reaching the goal in 2020. If we take into account the growth rate of the last documented years we could state that even though the rate has slowed down a bit in the last couple of years if the trend continues as it is, both goals will be achieved by 2020.



Graph 2.3. - Europe and Spain share of renewable energy evolution and targets [58]

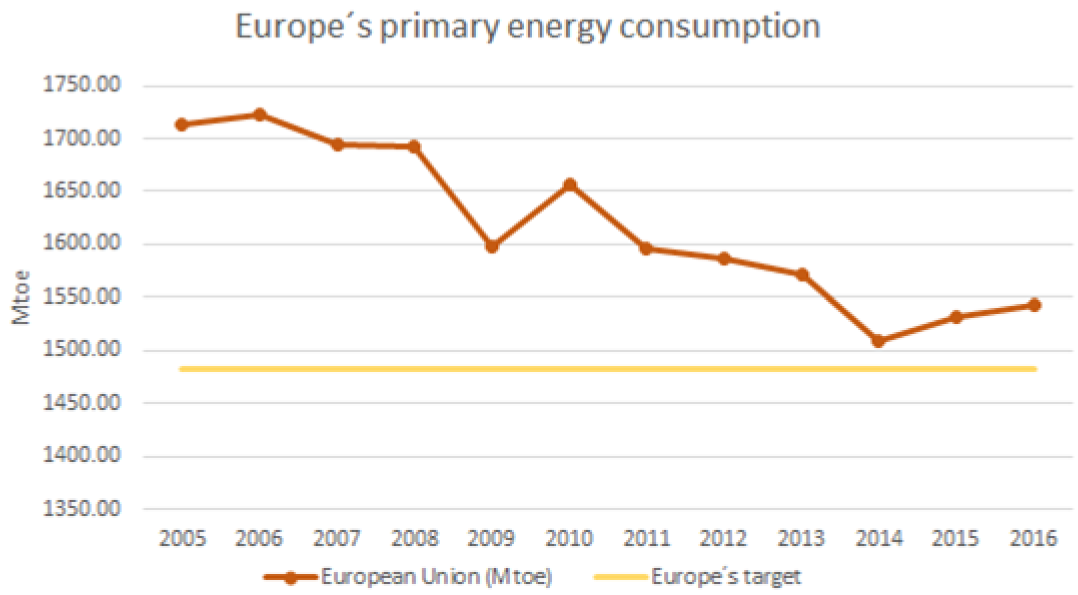
On the other hand, although the amount of renewable energy sources that are being install is increasing, and we are on track to meet the target; it should also be noticed that the process must also consider the total capacity. According to Red Eléctrica de España, the total capacity installed in Spain in 2017 was 104.115 MW, and the maximum daily peak is around 32-42 GW (the maximum value registered for 2017 was 41.381 MW on January 18th). It is true that we need to have more capacity install than the average daily peak, especially if the mix accounts with a lot of renewables but this goal of increasing the share of renewables should also consider uninstalling other nonrenewable generation systems to not incur even more in overcapacity. [8]

Energy efficiency

For energy efficiency, the 20% targeted is calculated using 2005 data as a reference and the projections for the 2020 primary energy consumption.

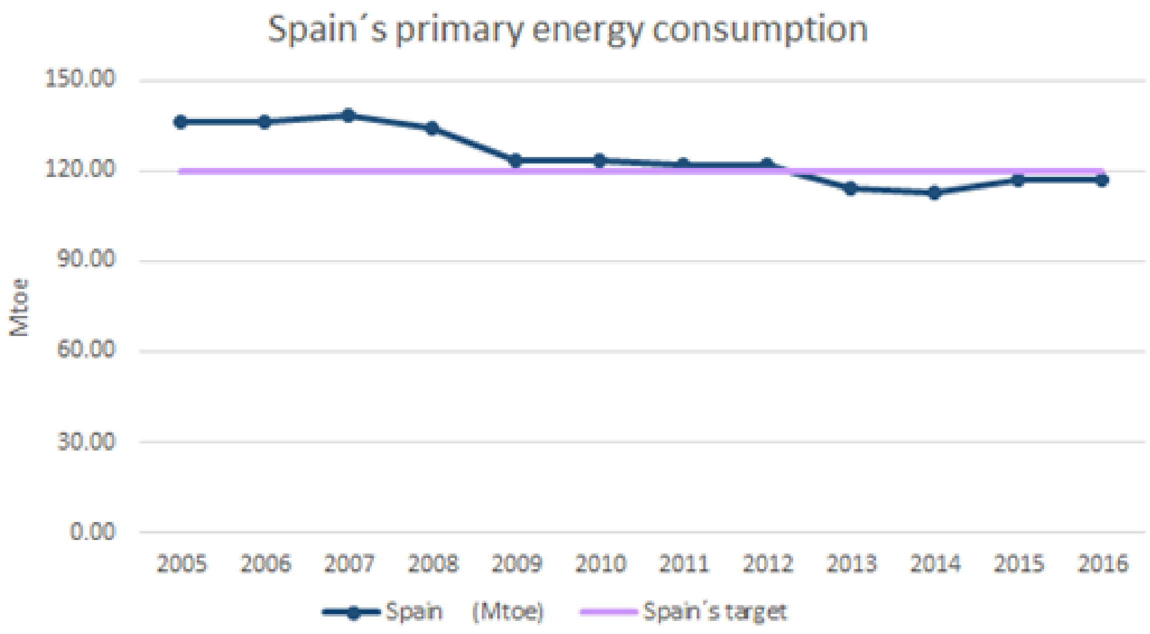
In the case of the European Union, we can point out an increasing consumption trend that started in 2014 and has been like that, at least until 2016 (most recent data collected). This sudden increase in the consumption gets away from the target value.

Taking into account the values of the last 10 years no prevision can be made on whether the consumption will lower down to the desired value by 2020 or not. However, drastic fluctuations regarding this value have been observed in the collected data, so achieving the target cannot be discarded.



Graph 2.4. - Europe evolution and targets of primary energy consumption [59]

In the case of Spain, we can extract from the data that the target was achieved in 2013. Although there was also an increase in the primary energy consumption in 2014, the values kept lying under the 2020 target. At least that was the case until 2016 (most recent data).



Graph 2.5. - Spain evolution and target of primary energy consumption [9]

2.2. Europe 2030.

In October 2014, the Europeans leaders adopted the 2030 climate and energy framework. Its mains targets are a progression of those established for 2020 and follow the same roadmap. The goals are:

	EUROPE
Share of renewable energy	at least 27 %
Greenhouse emissions reduction	at least 40% (1990 data)
Energy savings	at least 27%* *to be revised

Table 2.2. - Europe 2030 renewable energy, greenhouse emissions and energy efficiency [6]

Furthermore, in the case of energy savings, the European Commission, the Parliament, and the Council reached a new agreement in June 2018 which includes an update of the energy efficiency target for 2030. The new target is set at 32.5%, including a part of it to be met by 2023. However, this action has not been yet published in the Official Journal. [10]

Spain's targets

In February of 2019 the Spanish government sent to the European Commission the new plan and objectives for the period of 2021-2030. These objectives include a 21% reduction of the greenhouse emissions gases (having 1990 values as the reference). Data from the Spanish ministry for energy transition accounts for the values of greenhouse gas reduction to be around 18% already by the end of 2017. [11]

The 42% of usage of renewables in the energy consumed, stated in the mentioned plan, will reach the value of 74% by 2030. Also, PNIEC states that the energy efficiency of the country will improve by 39.6% in 2030. [11]

Furthermore, the period of 2021-2030 also coincides with those arguments made in the Paris Agreement.

2.3. Europe 2050.

2050 is the horizon for the future low-carbon, sustainable economy that the European Commission described in the 2011 Roadmap. For the moment, the goal that is being set is to reduce the greenhouse emissions by 80-85% compared to 1990 levels. The rest of the goals are not specific yet, they will be set when the horizon comes closer and the data enables to elaborate specific and achivable goals for 2050. [2]

3. THE SPANISH ELECTRIC SYSTEM.

Electricity is a necessity of all modern societies to carry out almost the totality of industrial, commercial, working and even living activities. It is crucial for their performance to have access to a reliable and secure grid and its vital to have an electric system that can provide it.

The electric system is the set of elements that are needed to generate, transport and distribute electricity to cover the demand of an area. In the case of Spain, the electric system covers the demand of all the mainland territory, both archipelagos and the cities located in the northern African shore and so it is divided into the peninsular electric system and the non-peninsular electric systems.

3.1. Electric system components.

An electric system is composed of generation centers, high tension lines, transformer stations, medium, and low lines and a control center to manage that the whole process is functioning correctly. In Spain, this control center is managed by the system operator, which is Red Électrica de España S.A. It is in charge of ensuring the continuity, security, and coordination of the different operations in the generation and transport of electricity. [12]

3.1.1. Generation.

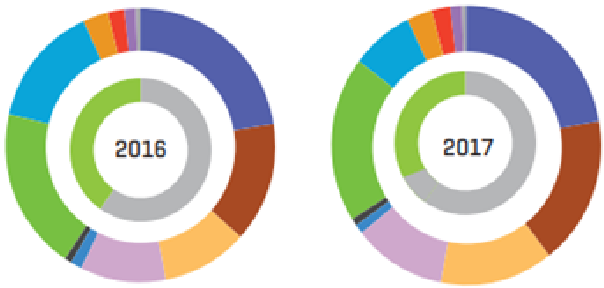
Generation is the production of electricity. It can be obtained by the transformation of primary energy and depending on what is this type of energy we can find different kinds of production plants. In these productions plants are where the process of supplying energy starts.

Depending on the primary energy source used to obtain electricity we can classify the production plants into non-renewable and renewable. The first type is defined as the ones that use sources that do not replenish in a short period of time. In addition, high emission of greenhouse gases is emitted in these processes. The renewable sources are less contaminant but not reliable.

In the case of Spain, the generation mix was the following for 2016 and 2017 (most recent data published by REE). [13]

Annual generation structure of the peninsular electricity energy 2016 y 2017 (%)

	2016	2017
NUCLEAR	22.6	22.4
COAL	14.2	17.1
COMBINED CYCLE	10.3	13.6
COGENERATION	10.3	11.3
PUMPED STORAGE	1.3	0.9
NON-RENEWABLE WASTE	1.0	1.0
WIND	19.0	19.1
HYDRO	14.5	7.4
SOLAR PHOTOVOLTAIC	3.1	3.2
SOLAR THERMAL	2.0	2.2
OTHER RENEWABLES	1.4	1.5
RENEWABLE WASTE	0.3	0.3



	2016	2017
RENEWABLE	40.3	33.7
NON-RENEWABLE	59.7	66.3

Figure 3.1. - Annual generations structure of the peninsular electricity energy in 2016 and 2017. [13]

The amount of energy generated by renewable sources decreased notably due to the reduction of production in the hydraulic plants. The amount of energy coming out of the hydro generation plants was reduced by almost 50% with respect to the previous year. Because of it, the amount of energy produced by coal and combined-cycle increased in order to meet the demand.

In 2018, according to the only data provided by REE at the moment this thesis is presented, the generation was 0.5% lower than that of 2017. Over all the production of carbon and combined cycled plants descended 17.2% and 18.9% respectively. [14]

Besides the generation, Spain is capable of exchanging energy with surrounding countries. These exchanges increased by 10.4% in 2017. However, although the exports of energy increased by 7.6%, the imports experimented even a higher increase that accounts for 12.2% higher than the values of 2016. The result is an importer net balance of 9.175 GW. The countries that import from us are Morocco and Andorra, Spain imports from Portugal and France. [13]

There are also some updates regarding the exchange of energy. The total energy imported was 11.102 GWh higher than that exported during the year of 2018. [14]

3.1.2. Transimission.

Transmission of energy is carried out by REE, designated as the only transport manager of electricity in the 17/2017 law. For this, REE is responsible for taking the electricity generated in the different generation plants to the distribution companies, sometimes to the end consumers and the interconnected countries.

In order to transport the electricity, the grid is composed of high-tension lines (above 220 kV), interconnection lines, substations, transformer stations (400 kV/220 kV), interconnections between the peninsula territory and the territories outside the peninsula as well as the connections between islands and several control elements.

The transmission grid kept improving in 2017, increasing the kilometers of line, the substations, and the transformer capacity.

	2015	2016	2017
Kilometers of line (Km)	42,989	43,646	43,793
Substations	5,428	5,491	5,601
Transformation capacity (MVA)	84,544	85,444	86,654

Table 3.1. - Spain transmission system characteristics. [13]

The only data published to the date of elaboration of this thesis by REE regarding 2018 states that during that year 277 new kilometers of line and 2,592 MVA of transformation capacity in different substations. [14]

Furthermore, the service quality indicators show the quality of the grid and the security of supply of the system. In 2017, the ENS (energy not supplied) accounts for 60 MWh, 18MWh less than the value for 2016. Also, the AIT (average interruption time) was 0.13 minutes, 0.03 minutes less than in 2016. [13]

3.1.3. Distribution and commercialization

The distribution of electricity is the action of transporting electric energy to the end consumers or to other distributors. The distributor must ensure the quality of this transmission, which is carried out by lines below 220kV, the correct functioning of transformer stations as well as the good reception by the consumer.

The distribution companies form a natural monopoly in the national territory, each of them supplying electricity to different territories. The main five distributors in Spain are Endesa Distribución, Iberdrola Distribución, Unión Fenosa Distribución S.A., Hidro-Cantábrico Distribución S.A.U. (inside EDP) and E.ON Distribución. The end consumers are not actually their clients, they just have to supply the electricity to them.

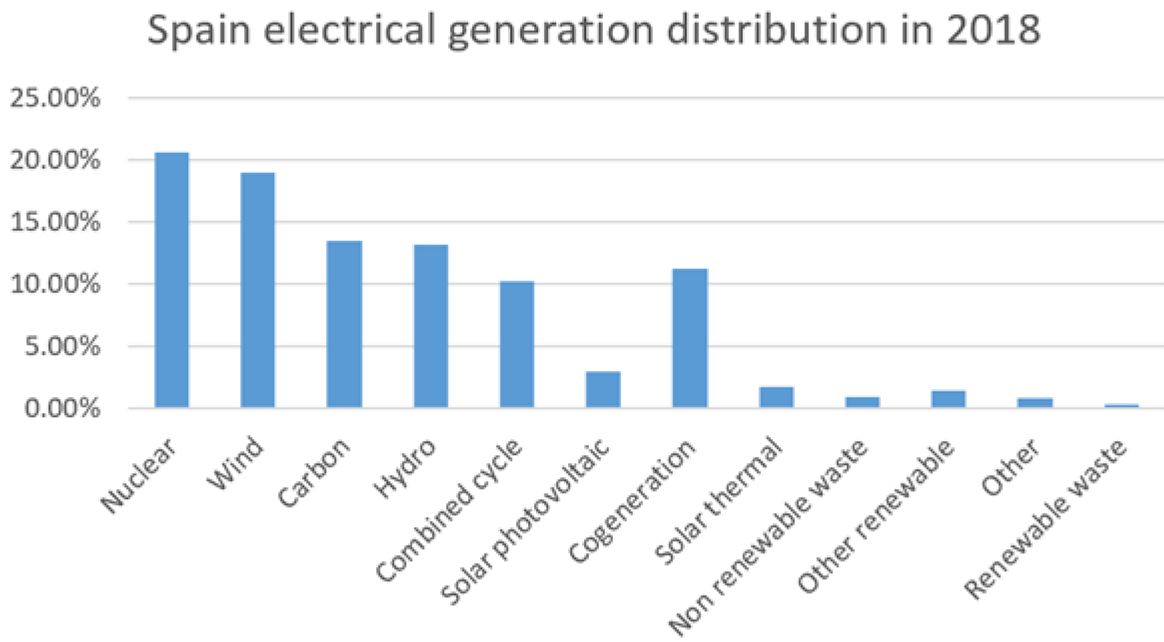
On the other hand, since 1997 when the law 54/1997 established the liberation of the electricity market, the distribution company does not have to be necessarily the company that sells the energy to the end consumer. The end consumers have more companies to choose from, making the market more competitive. In 2009, the government established a temporary tariff (TUR) to increase the stability of the market, which does not exist anymore. [15] Nowadays there are 525 commercialization companies listed in CNMC (National Commission of the markets and competitiveness). [16]

3.2. Consumption

Consumption of the electricity is the last step. Nowadays we are starting to use electricity more and more in our daily lives so the demand keeps growing.

3.2.1. Data of 2018

The consumption of electricity in Spain in 2018 has grown for the fourth year in a row. According to the report of REE the total consumption for Spain was of 268.808 GWh, which is 0.4% higher than that of 2017. According to the report 40.1 % of the demand was met by renewable sources, which helped reducing the amount of greenhouse gases released to the ambient.



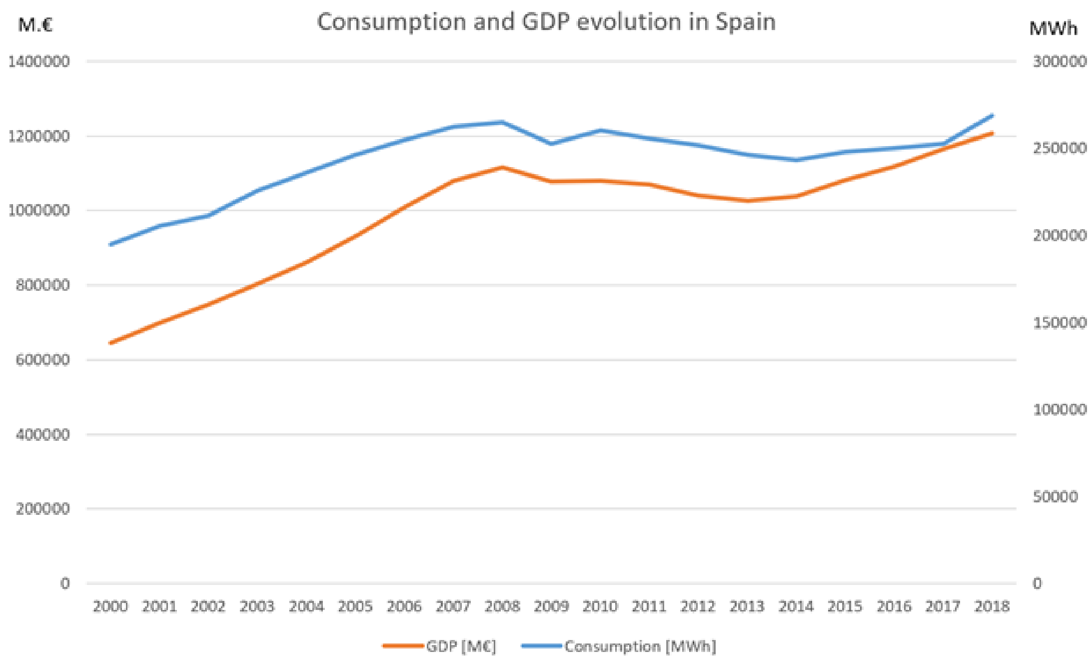
Graph 3.1. - Spain electrical generation distribution. [13]

As seen in the figure, even though the majority or the demand was met with conventional sources, some renewable resources have already a big share of the energy mix, accounting for a total of 40.1% of the energy consumed. [14]

3.2.2. Evolution of consumption and GPD correlation

As seen, it has been proven over time that there is was a direct correlation between the electric consumption of a country and its GDP. The GDP (Gross Domestic Product) of a country is a good measure of the quality of life of its inhabitants and the amount of industry that it has. Both of these factors were directly correlated with the consumption of usage, industry is the sector that consumes more electricity and so it can be appreciated that both factors increase and decrease at the same time over the years. [14] [17]

In the following figure it can be appreciated how this correlation takes place in the case of Spain. In the first years of the century it can be appreciated in the graph how the correlation between the electric consumption and the GDP of the country was taking place. It is worth mentioning the influence of the recession that took place around 2008, where there was the first fall, and both kept decreasing until 2013.



Graph 3.2. - Consumption and GPD evolution in Spain. [18] [14]

Furthermore, it can be appreciated that the correlation between these two factors started to fade after 2013. The annual variations of both started to change at different rates. This change was probably initiated by the recession, a period in which the companies had to adapt. Also, the technological advances have provided an increase in the efficiency, and so helped controlling the increase of the economic consumption compared to the increase in GPD.

3.3. Electric market

The electric market used to be regulated by the Government until 1997, when the Law 54/1997 was approved, stating a liberalization of the market. Before this point the price of the electricity was set by the state. From this point on, some activities where liberalized such as the generation and the commercialization whereas others where maintained as a monopoly such as transport and distribution.

Also, Red Eléctrica de España S.A. was established to be the system operator of the network and the only agent in charge of the transmission system of electricity. The market that regulates the electricity in the Iberian Peninsula is MIBEL (Mercado Ibérico de la Electricidad) contains the wholesale and the retail markets. Furthermore, the market is composed by Spain and Portugal; on one side the market operator of the Portuguese side of the market (OMIP) is where the future prices of electricity are negotiated days, weeks or even months in advance, while the market operator of the Spanish side (OMIE) is the one where all the transactions of the day and intraday markets. The adjustment services are managed by the system operator, to fix any momentaneous problem that the grid might have.

Ancillary services

The transmission system operator is also the agent in charge of guaranteeing the security of supply through the correct coordination between the suppliers, grid and demand at every moment. [19]

In order to guarantee the correct functioning of the grid, Red Eléctrica de España relies in the ancillary services to overcome the technical restrictions that the system may have. The complementary services are identified as:

- Additional Upward Reserve Power. It is optional and managed by the market mechanisms. Its function is to provide the system with a sufficient capacity to be in reserve, taking into account the forecast for the day-ahead.

• Secondary Control Band. It is optional and its function is to maintain the balance between production and demand at all times, managing the deviations respect to the forecast. It can act from 20 secs to 15 min.

• Tertiary control. It is the maximum variation of energy that a supplier can make in fifteen minutes and that can be maintained for two hours. It is optional and its function is to complement the secondary control band if the deviations persist.

In the following image we can appreciate the amount of energy that was produced or had to be stop producing along the 2017 by each ancillary service. The upward energy refers to the energy that has to be produced by the system when the forecast for demand was larger than expected and the systems needs to lower its production. The down energy is the opposite case; it refers to the energy that the system should produce when the forecast was short. [19]

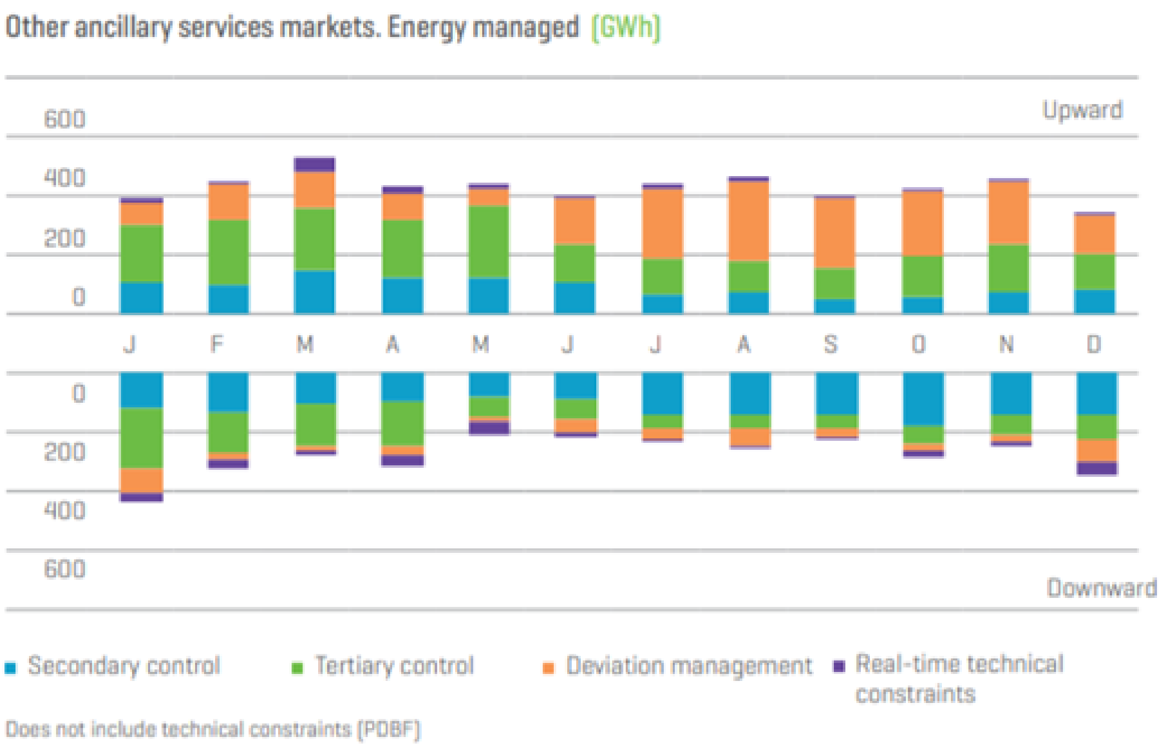


Figure 3.2. - Ancillary services market in 2018 [20]

The deviation management is another optional service whose function is to solve the deviations between production and demand that are higher than 300 MWh, that are usually given at the closure and opening of an intraday market period. The real time technical constrains are the mismatches solved by REE at the moment of operation. The transmission system operator modifies directly the amount of energy produced by plants.

Finally, in the next figure we can appreciate the contribution of this different tools into the final price of energy. The capacity payments are the regulated fees that are offered by the suppliers in order to maintain in the long-term the capacity service. A discussion about interrumpibility will be provided in the following chapters.

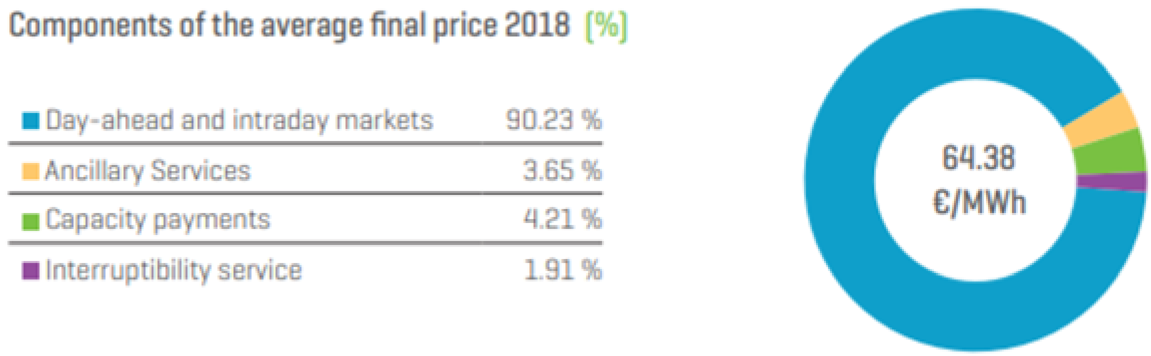


Figure 3.3. - Components of the average final price 2018 [20]

As it can be appreciated, almost 90% corresponds to the day-ahead and intraday market, and the other 10% is a compound of all the mechanisms that ensure the security of supply.

3.3.1. Wholesale market

OMIE manages the wholesale or spot market of the Iberian Peninsula. It is the one ensuring the trading of energy among the different agents. The main markets that it is composed of are the daily and intraday market as well as the adjustment services.

Regarding the daily market, the price of electricity in Europe is settled everyday at noon for the following day. The calculation of the prices is done using the algorithm EUPHEMIA, used in many European countries. The buying and selling agents can trade in this market regardless if they are in Spain or Portugal until the interconnection channel is fully occupied. As long as the interconnection channel is not at its maximum capacity the price in Spain and Portugal remains the same. This is the case more than 90% of the time. [21]

However, due to the characteristics of electricity, the forecasted demand and production can be altered, and the system operator must balance them, and so prices might change.

The intraday market consists of six trading sessions every day, so the agents can readjust their position to be more competitive only up to four hours in advance. It is a way of compensating for the changes in the forecasts. Besides the national intraday market, OMIE participates in a continuous intraday market in Europe, XBID, since 2018.

Finally, the adjustment services are those used by the system operator to match exactly the demand and the generation and might include some technical restrictions.

3.3.2. Retail market

The commercialization of electricity was totally liberalized in 2009, where the integral generation tariffs are completely extinguish leaving only the last resource tariff (TUR) as a regulated pricing options for consumers whose contracted power is below 10 kW. The latest royal decree approved in 2014, suppresses the last resource tariff in favor of the voluntary price for the small consumer (PVPC) that consist of the energy consumed, the contracted power and the access tariffs. [22]

4. ELECTRIC DEMAND

Electric demand can be defined as the rate at which electricity is consumed. It is measured in kilowatts (kW). This demand varies every second in every household or industry depending on how many lights and appliances are on or how many machines are working. Extrapolating these values to the whole country, it can be appreciated that demand is very hard to control since it varies every second and it must be forecasted and met properly not to cause a blackout.

Furthermore, it is important to make the difference between demand and consumption. The latter refers to the amount of energy that is consumed over a period of time, and it is measured in kWh. This thesis will focus on finding the ways in which demand response could be used as a tool for operations in real time. One of the ways of achieving this flexibility could be reducing the overall consumption that will be a permanent change in the average demand.

4.1. Spanish electric demand curve

The electric demand curve in Spain has a particular shape that keeps repeating with small fluctuations over the days. It can be broken down by sectors into industrial, services and residential in a day based.

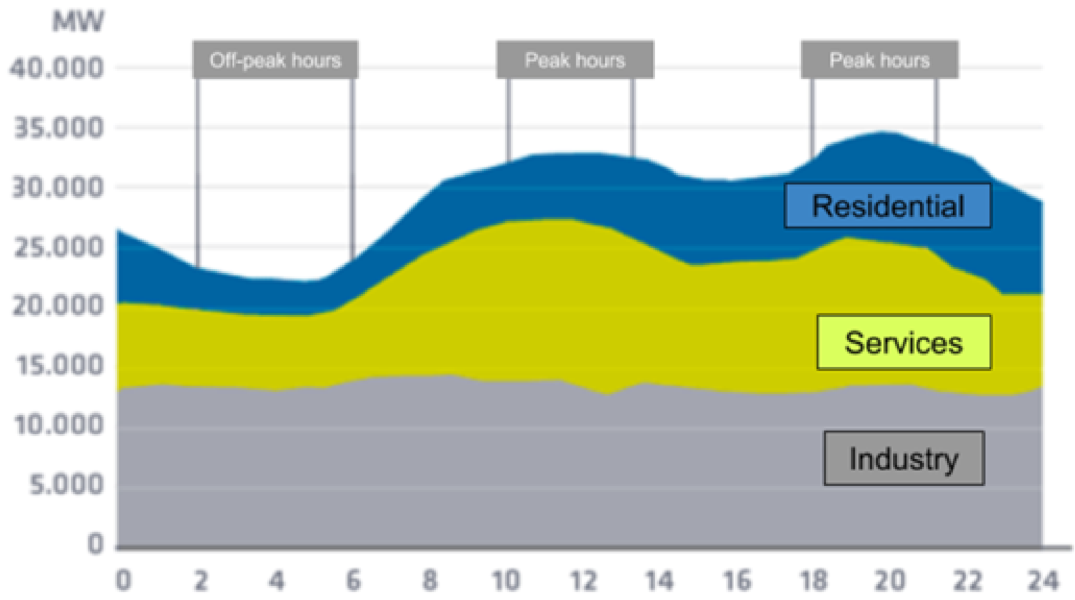


Figure 4.1. - Electric demand distribution. [19]

The industrial sector almost has a flat and constant demand due to the factories working all day long. The services sector follows the normal working hours during the day, starting to increase at 7:00 am with the start of the working hours and decreasing after at 20:00 pm when people are turning back home, and the shops are closing. These activities create the peaks and off-peak. Finally, the residential factor is the one that ends accentuating the shape of the demand.

That being the case, it is very important to learn ways to modify the consumer habits in the services and residential sector because those are the sectors where the peak and off-peak are created.

These fluctuations create the challenges that the system operator has to face as the high ratio that exists between the peak and the off-peak hours that requires a strong system, and the low values during the off-peak hours that sometimes require the wind energy production to be curtailed when the demand is not high enough.

In the case of Spain, there are around 100 MW of installed capacity. Of which, 41,38 MW was the maximum annual value of 2017 coinciding with the peak hours of January 18th. [13]

4.2. Demand evolution and factors that influence it

The evolution of demand in recent years has not been stable. There was a slow growth from 2006 and 2008 and the value in 2009 dropped drastically. There was a fast recovery in 2010, although from then until 2014 there was a decreasing trend. In the last years there has been a slight increase trend and in 2017 the demand grew 1.1% with respect to 2016. [13]

The evolution of the growth of demand is influenced by many factors. As an example, the drastic decreased of 2009 was very much influenced by the economic recession the country was facing at the time. Economic growth or recession of a country is strongly linked to electricity demand. This factor can make long-term changes in demand influencing the trend that it follows annually.

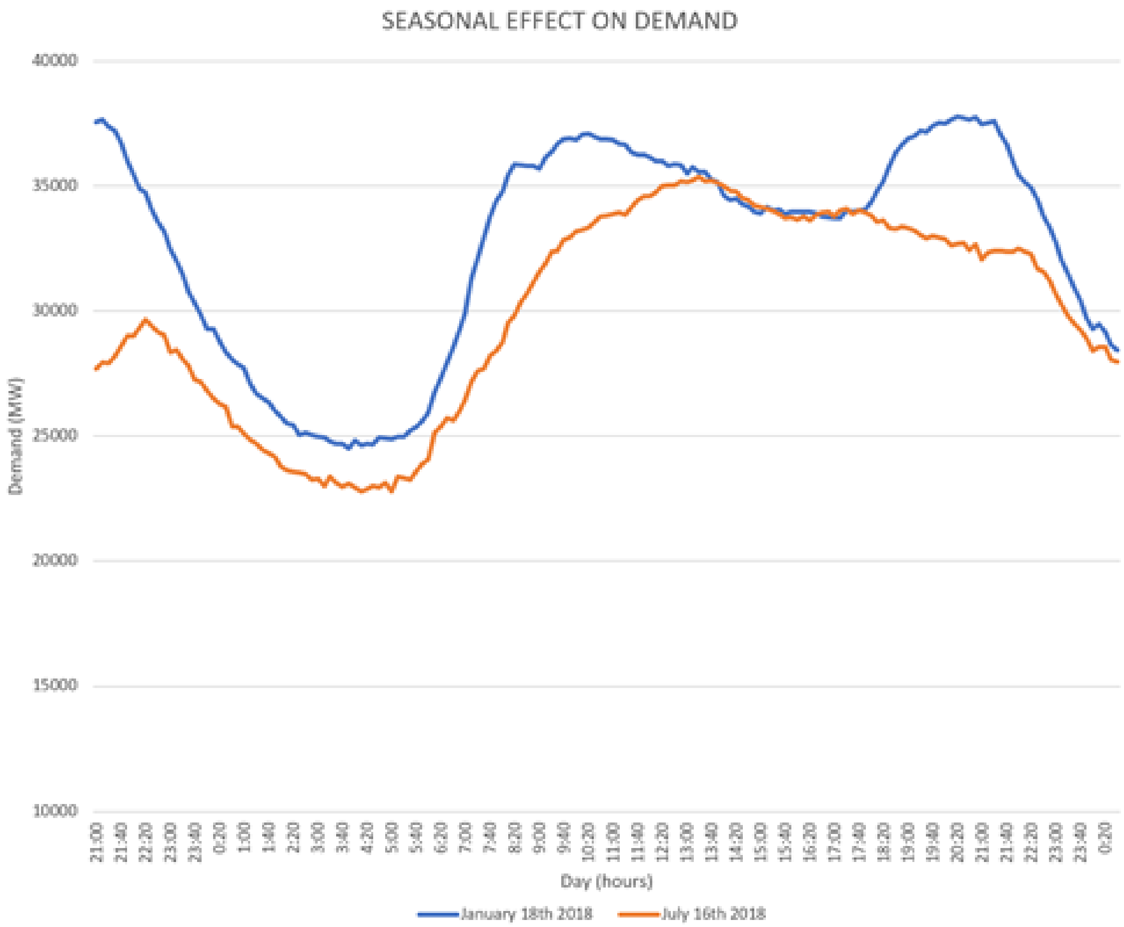
However, there are other factors that can change slightly the behavior of the demand from year to year.

Factors that affect demand

Temperature and cloud coverage can affect the annual demand. A fluctuation, either of hot or cold temperature over a period of time, will increase the use of heating systems and air conditions by the residential and services sectors and will cause the demand to increase or decrease depending on the case.

As an example, the year 2017 had 43.4% of days whose temperature was higher than the historical average. This caused the demand to increase during the summer season and decrease during winter. Following the data provided by REE in the 2017 Annual report, the temperature influenced the demand as to decrease demand growth by 0.2%. The temperature has a visible effect on demand in the short term, but if consistent it can make annual differences. [8]

However, these seasonal differences can also be spotted in the daily demand of a summer and a winter day.

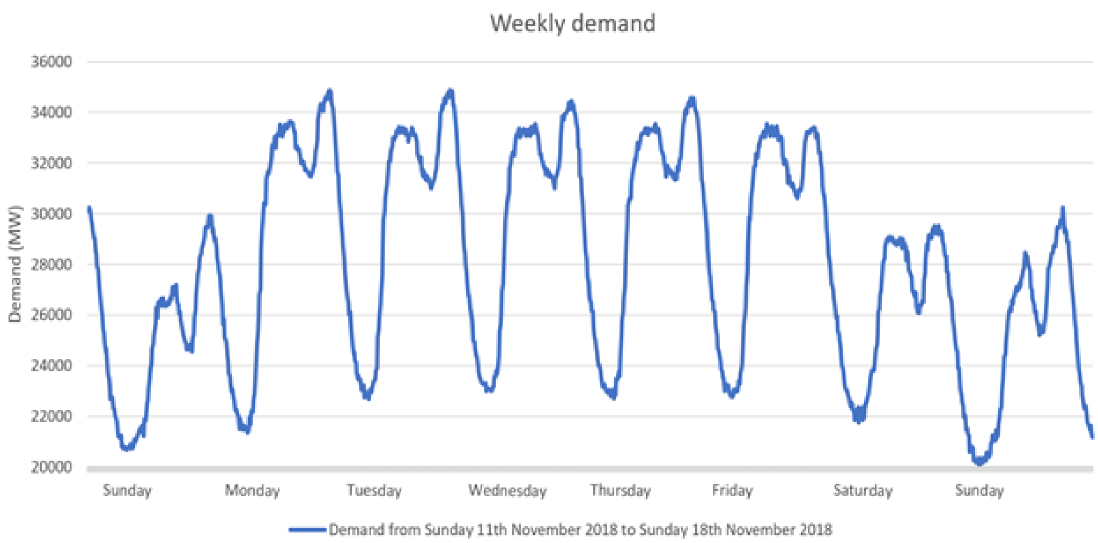


Graph 4.1. - Seasonal effect on demand [19]

During the summer, the peak hours concentrate in the middle hours of the day, where the heat is maximum and the air conditioning is most used. Also the off-peak is very low during the night due to the lack of need for air conditioning since the summer nights are cooler. The following image corresponds to the data of July 16th, 2018. It can be spotted that the peak is constant in time during the central hours of the day and so there is just one peak and one off-peak.

On the other hand, during the winter the peaks concentrate in the very early morning, where the steep is much more pronounce and later in the evening. These two periods are usually the ones with the coldest temperatures so the heating systems usage increases. There is a small off-peak in the middle of the day when the sun usually makes the temperatures more bearable. Also, the off-peak at night is not as low as those in the summer time since some heating systems are kept on during the night. The image corresponds to the demand curve of January 18th2018. The two peaks and off-peak can be appreciated.

As for the daily demand, other factors that affect are labor days, holidays or special events such as demonstrations. The habits of consumers change during these types of dates and that affect the daily demand. A clear example is weekends where many businesses are closed and so the demand is lower than the rest of the week.



Graph 4.2. - Weekly demand [19]

The imaged shows the weekly demand from Sunday 11th November 2018 to Sunday 19th November 2018. The influence of the calendar is usually in the short-term and it is quite easy to predict since it is known in advanced.

4.3. Electric demand forecast

Forecasting the electric demand is an essential part of the duties of the system operator. The demand needs to meet the generation at all times and although the adjustment services are the ones in charge of doing it in real time, a forecast in advance will help to prepare for it. By preparing a more precise forecast, the system becomes more efficient and the emissions are reduced since the use of renewables can be optimized. [8]

To carry out the forecast, complex algorithms use historical values of those dates in the previous year and the recent day's values, as well as the seasonal load and the working calendar.

The forecast on the image, in green, does not differ much from the final real demand but for small fluctuations. The programmed demand tries to be as close to the forecast as possible and the adjustment services will make the generation meet the demand.

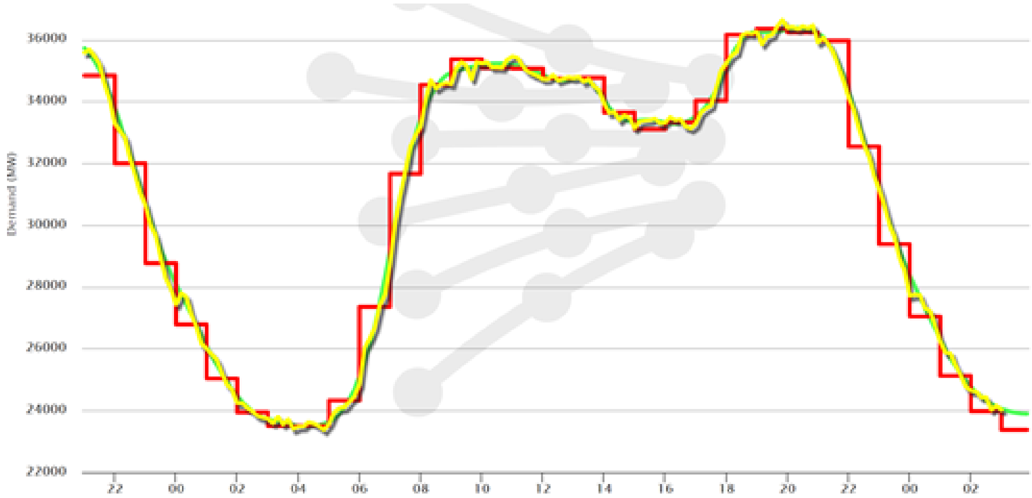


Figure 4.2. - Real, forecast and programmed demand. [19]

Red Eléctrica de España conducted a research project to improve the algorithm used to forecast it. It was carried out with the collaboration of two spanish universities and was finished in 2016. As a result, the reliability of the process has increased, and the mean squared error has decreased by 0.25% in the peninsular forecasting.

5. DEMAND SIDE MANAGEMENT

According to IEEE: *"Demand-side management encompasses the entire range of management functions associated with directing demand-side activities, including program planning, evaluation, implementation, and monitoring"*.(IEEE, 1985) So, it is the planning and implementation of all measures that try to impact the way that energy is consumed. [23]

5.1. Aim

The ultimate goal of demand side management is to change the demand load shape into one that is more flexible, that enables the operator to use demand response as a tool. Demand response refers to all the programs design to short-term reductions of demand for a short period of time. Demand side management includes any program that helps the end-consumer be more efficient, and so, add flexibility as demand response programs do, and modulation through other actions that ensure a permanent change.

This goal is achieved by changing the daily load shape that is making permanent changes on it, and by adding the possibility to change the demand on the short term. The way to produce those changes is through the modification of the consuming habits that could be possible thanks to the participation of end consumers with the help of awareness, incentives, and technology.

5.2. Challenges

The duty of demand side management is to make the system more efficient in modulating the demand. This is necessary because the current system is not efficient: during the peak hours, the electricity is more expensive because some generating plants that usually do not function have to do so to meet the demand, and their offer prices is higher. These plants produce with a higher marginal cost and usually produce more CO_2, so the price increases overall. Also, during the off-peaks, the demand is so low that sometimes wind generation has to be curtailed to protect the system.

To solve these problems, four different challenges have been identified and some initiatives to solve them have been proposed. Implementation of several of these solutions is what could potentially make a change.

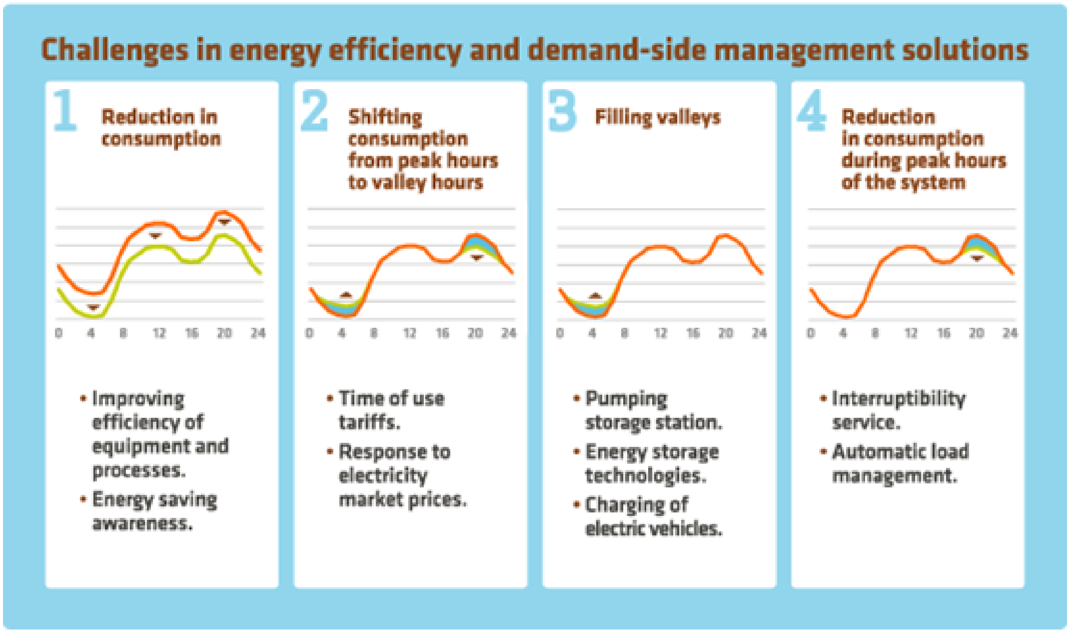


Figure 5.1. - Challenges in energy efficiency and demand-side management solutions. [8]

5.2.1. Reduction in consumption

An overall reduction in consumption will increase the efficiency of the system. However, as seen in previous chapters, the trends for electricity demand and consumption are now growing, even at a slow pace. So, reducing the consumption that it is growing requires new, more efficient technology and consumers' commitment.

Equipment and processes increased efficiency

More efficient equipment and appliances will reduce the amount of electricity consumed without changing the habits of the population. However, the transition to more efficient appliances has to be somehow pushed by authorities since in some cases it is expensive for the suppliers and the end consumers to change their products into more efficient ones without stop being competitive (due to different materials, or longer processes). So, this is indeed a great part of the solution to the problem, but it cannot be the only one since new processes and new appliances that do not exist now are yet to come. Modern society is gravitating towards a more digitalized and more connected world and the technology that will make that happen would also need smart grid.

Social awareness on the importance of saving energy

Another key element to achieve a reduction in consumption is to increase the awareness of energy efficiency to the population. Through education, society should learn about the current situation and the role they can play from their individual consumption to be more efficient.

5.2.2. Shifting consumptions from valley to peak

A different way to modulate the daily demand without reducing the consumption would be to shift some of the consumption from the peak hours to the off-peak. These type of actions will flatten the demand curve and so, make it more stable and easier to forecast.

Hourly discrimination tariffs

Thanks to the smart meters implementation, more accurate pricing schemes have been developed. Varying the price of electricity depending on the time in which it is consumed enables the system to send price signals to consumers, so they charge the off-peak hours at a cheapest price than the peak ones encouraging consumers to use electricity when it is cheapest.

Some of this time-based pricing schemes are:

- Time-of-use tariff (TOU): this pricing schemes set different periods within the day and the time of the year, including modifications for season and the labor calendar. The periods cover several hours and its prices are constant and known in advance. This system is used in Spain and Czech Republic along with real-time pricing, which is explained below. [24]

- Real-time pricing (RTP): in this case the rates are applied to the consumption hour by hour. [24]

- Variable Peak Pricing (VPP): it is a mix between TOU and RTP because there are periods defined in advance but the price of the energy during the peak it is different depending on the utility and the market. [24]

- Critical peak pricing (CPP): in this type of rate when the system operator anticipates problems on the grid increases the price (usually of the peak) to discourage the consumption. This system is used Slovenia. [24]

- Critical peak rebates (CPR): in this case, when problems (security or economic) are anticipated the rate for consumption keeps equal but the consumers that reduce their consumption relative to what the utility predicted that would be are refunded. [24]

All these pricing schemes aim to modulate demand in the long term and add some aim to add some flexibility for punctual occasions.

5.2.3. Filling valleys

One of the big challenges that we face today is the curtailment of wind power during off-peaks. The demand is so low that not all the energy that is being generated is needed and due to security reasons, there are certain generation plants such as the nuclear plants that cannot be easily stopped. So, generally wind energy, which could be providing electricity if there is enough wind, must be curtailed if the demand is not high enough. The possible demand side management actions are:

Pumping storage stations

Some solutions for this problem have been used for years. One of them is using pumping storage stations where that are usually integrated into the hydroelectric power plants. They work as a normal hydro generation plant during the peaks, but during the off-peak, when the price of energy is the cheapest, they use a pump system to bring the water in the lower reserve back to the higher one. When the price goes up again, it keeps generating and selling energy.

Batteries as a form of domestic energy storage

Another possible solution to this challenge is to keep the energy that is generated at the cheapest hours to consume latter when the demand and the prices are higher. Although storing large quantities of energy is another challenge that has not been technically achieved quite yet, there are many projects and companies investing in the development of batteries that could at least provide the service of storing the cheapest energy for a household.

Lithium-ion batteries seem to be the next disruptive technology in the energy sector. According to McKinsey, it seems like the capacity of the batteries is expected to continue growing while its prices get lower. [25] If this forecast is right and the trend continues as it is, domestic storage could be an economic and technological fissile way to modulate demand. This type of storage could also be an incentive to keep installing self-consumption.

Electric vehicle implementation

Furthermore, the total implementation of the electric vehicle is also seen as an opportunity to increase the consumption during the off-peak hours. Most of the electric vehicles would be charge along the night, so controlling that consumption could avoid the need to curtail certain generation plants because the demand is not high enough. The possible use and factors that should be considered in the total integration of the electric vehicle would be detailed in the next chapter.

5.2.4. Reduction of high peak

Finally, the last challenge to be faced is the reduction of the high peak. Having a very high peak of demand only during a short period of time is a risk for the system as well as very inefficient. It is a risk because the system should be well integrated and ready to increase the amount of energy that it is coupling in a very short time, so the response time must be small in order to avoid a black out at all times.

At the same time, it is inefficient because for the system to work properly during this small period, a lot installed capacity is needed. Currently in Spain the demand during the peak hours is around 40 MW, and the capacity installed is around 100 MW. There is a need for the installed capacity to be much greater than the average peak demand because not all the power can be generated at once. For example, the variability of some renewable plants or the maintenance activities of other plants might make some of that capacity unable to produce at certain times.

Interrumpibility

The interrumpibility service has been used as a measure to decrease the risk for a black out of the grid for a very long time. It provides a fast response to the specific need of the electrical system. It consists in the fast reduction in consumption in a particular instant in which the demand is too high respect to the generation. It can be applied for security and for economic reasons.

This service is primarily intended to be provided by big industries, whose reduction in consumption in key moments can really make an impact on the required demand. There are different products for interrumpibility, each of them accounting for different amounts of energy and time to be stop.

A further explanation of the application of the interrumpibility services in the different countries will be addressed in the following chapters.

Automatic load management

Automatic load management consists of reallocating the load of a certain device to make it more efficient. It will distribute the load along the time that the device is connected in order to evenly distribute in time instead of producing a peak in consumption even if it is at a low scale.

6. DEMAND SIDE MANAGEMENT IN SPAIN

In this chapter, we will first approach the measures that have been in force in Spain for quite some time and then we will assess some of the possible future actions for demand side management that are either just starting to develop in Spain because the regulation changed recently or that could be develop in the medium-term.

6.1. Implemented actions

Eventhough demand-side management seems to have appear recently with the latest generation of smart meters, the truth is that some measures have been in force for quite some time, providing some modulation to the demand for security and economic reasons.

6.1.1. Awareness

This education is now more accessible to end consumers that thanks to smart meters, because they have access to the detailed information of their consumption through their distributor web and learn about the regulated prices in the web of Red Eléctrica de España. Currently, almost all homes in Spain have smart meters as seen in the following figure:

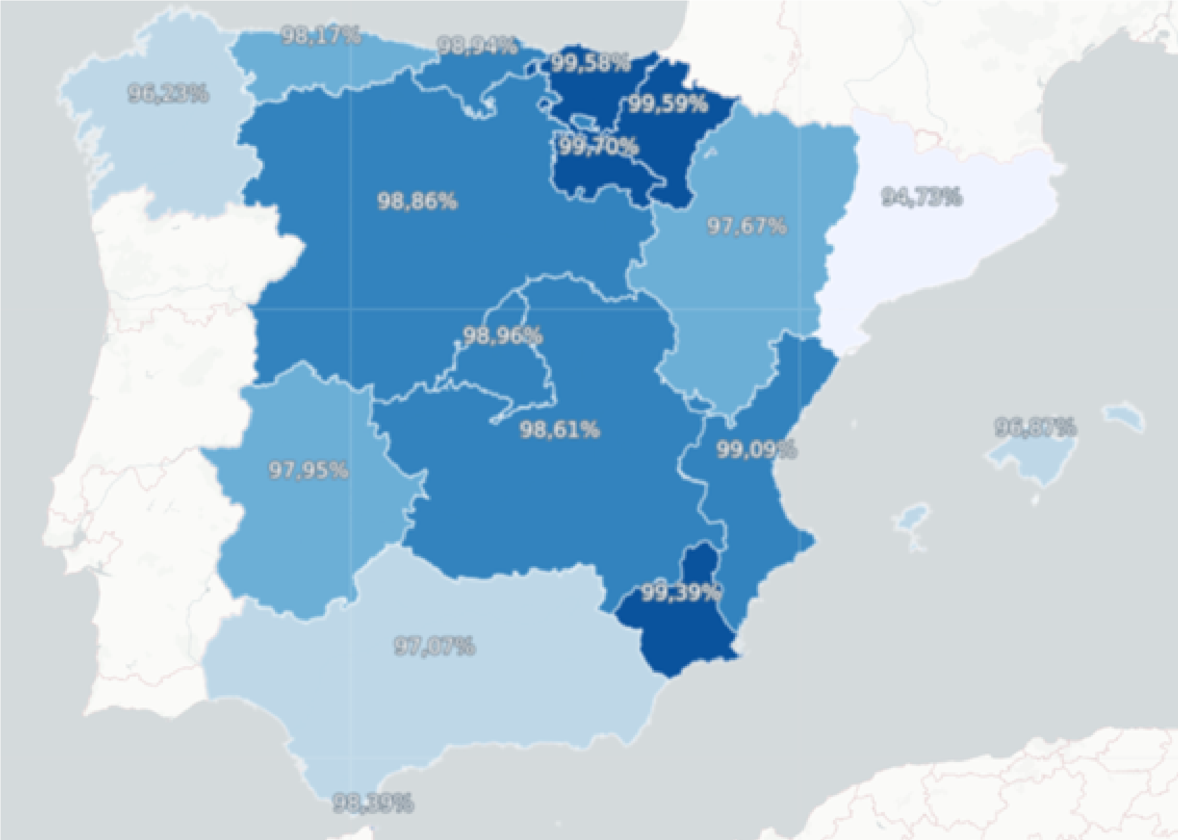


Figure 6.1. - Smart metering devices in Spain. [60]

Also, many institutions as REE have published smart consumption guides to help society understand how our system work, what are the peak and off-peak hours and how to change some habits to a more efficient consumption.

6.1.2. Hourly discrimination tariff

The implementation of smart meters have also enabled consumers to price their electric bill based on their consumption hour by hour. This, as explained in the previous chapter aims to shift the consumption habits.

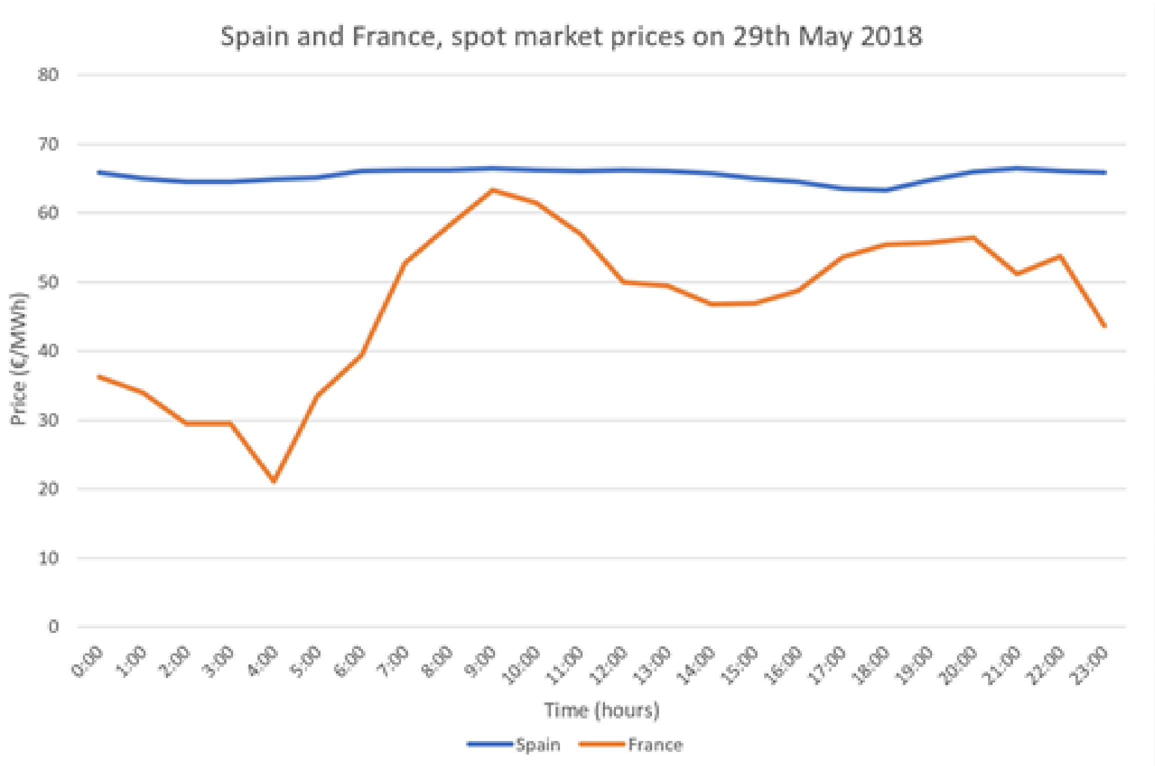
In Spain, there are different types of tariffs that divide the day in two, three or six periods. In order to contract a certain type of tariff some conditions should be met regarding the contracted power and the voltage, ensuring that each of these tariffs is aimed and contracted by certain types of consumers. The specifications for each tariff along with the delimitation of hours for each period are published by the government in the

BOE (Boletín Oficial del Estado). It was covered by the Royal Decrete 1164/2001 in the BOE-A-2001-20850 and the last modification was published in the 30th December 2006. [26]

In Spain, in the case of the two period tariffs is aimed to residential consumers and it differentiates the off-peak, night hours to the rest of the day. The tariffs with three periods include a third price, set for the night time as a super off-peak tariff and was intended as a way of encouraging the electric vehicles charging. Finally, the six-period tariff is aimed to industries and the periods also take into account labor factors.

The differentiation of what are the hours that belong to each period also depends on the system (Peninsula, Canarias, Baleares or Ceuta and Melilla) and they are settled and published by Red Eléctrica de España S.A.

However, the price differences are not always well differentiated in Spain and that is huge disadvantage to encourage consumers to modulate and adapt their consumption.



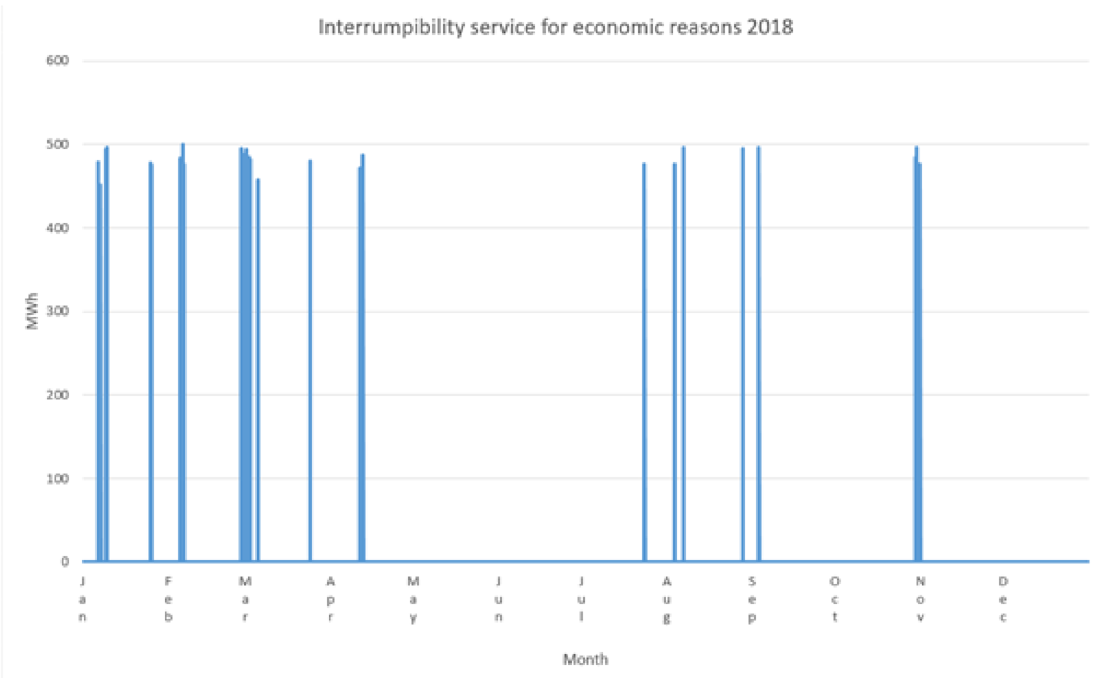
Graph 6.1. - Spain and France spot market prices. [8]

In this figure, we can appreciate the difference in the electricity prices between the Spanish and French markets. Setting aside the overall difference between them, it should be appreciated how the French market adapts their prices to their demand in a more efficient way while the Spanish market sometimes does not send any price signal to the consumers. One of the possible explanations for this could be the minimum income condition; this condition establishes that a generation unit can offer anytime without participating in the matching of the day only if the total production of the day of that plant is lower than an established amount and a variable term for the energy produced, all expressed in euros. [21]

6.1.3. Interrumpibility

In Spain, this service can be activated either for technical or economic reasons. In the first case the service is provided in emergency situations as a security measure, and in the second case it is provided to reduce the costs of the system.

In 2018, the interrumpibility service was requested a total of 50 times for economic reasons.



Graph 6.2. - Interrumpibility service for economic reasons. [60]

The service is activated when REE sends a signal to the big industries to stop their consumption for a period of time. The big industries receive a retribution for providing the service. The norm IET/2013/2013 provides the instructions on how to manage the bid to assign this service. The bids are controlled by REE and there are two types of products: 5 MW and 40 MW that are assigned to the industry that can provided it at a lower cost. The bids are held twice a year. [8]

This service is relevant in the peninsular system because even though there are other preventive measures; the system is not well interconnected so the interrumpibility service is very much needed as a last resource to protect the system. Furthermore, in the systems of the islands this preventive measure is very important because the systems and subsystems are isolated.

The past year 2018, was the first time that the bids to assign the interrumpibility service were held twice instead of once. The last bid was held from the 10th to the 12th of December of 2018, where the interrumpibility services for the first semester of 2019 was assigned. The bid assigned 2600 MW to 124 consumers for a total cost of 101,15 million euros. [8]

6.1.4. Storage

In this section we will revise the main forms of energy storage implemented in Spain.

Pumping storage

Currently, the largest hydroelectric plant in continental Europe with integrated pumping storage is located in Valencia, Spain. The two stations, La Muela I and La Muela II, properties of Iberdrola have a total installed capacity of 1767 MW. [27]

Also worth mentioning is the Chira-Soria reversible hydroelectric plant in the Canary Islands. Its construction has just been adjudicated by REINCAN (the REE filial). The plant will have a rate power 200 MW, which is 36% of the actual peak demand of the islands. This project will increase the security of supply, security of the system and the integration of renewables. [8]

Batteries

However, some research processes are experimenting on the possibilities to install storage at a larger scale. ALMACENA project by REE in particular, studies the installation of a battery in the Carmona 400/220kV substation. The ion-lithium battery of 1 MW was installed at the end of 2013 and REE has checked that it is a feasible option in the future and compares its performance and cost with other technologies pf storage.

6.2. Possible future demand-side management actions

Besides the measures that have already been discussed in the previous chapter, there are other possible actions that can be consider as good options for demand side management.

Some of them are already starting to be implemented in Spain and others are in other countries. The goal of this chapter is to study how these measures work and how could they be implemented or improved in order for the system to fully take advantage of them.

6.2.1. Aggregation

Currently the only demand response mechanism that we have in our system is the interrumpibility service and it has already been discussed that it is only used to supply security to the system because it is able to add flexibility in a very specific moment.

Aggregation is another demand response mechanism that focus on providing a continuous service that could not only provide some flexibility to the demand curve in a specific moment but also add some modulation to the curve over the time. The other big difference is who the service is aimed to. Big industries, in exchange of a quite large fee, can stop their activity for a short period of time, but cannot really compromise their production in a continuous way or they would not be profitable. On the other hand, smaller consumers, whose activities regarding the use of electricity are not always crucial could compromise themselves to follow a certain profile of consumption or even provide an interrumpibility service for a price or a reduction in their bill. However, one single consumer compromising their maximum consumption or interrupting it at a certain time does not have any impact on the system. [28]

Aggregators are the figures that act as intermediaries between many small consumers of certain areas that are willing to provide the service and the system operator that is the one matching the demand and the generation at all times, managing the ancillary systems and asking for interrumpibility in case it was necessary. The union of consumption of many small consumers can certainly have some impact in the system.

Red Eléctrica de España has conducted the AGREGA project by which it has been demonstrated that there are no technological barriers that could prevent from using this form of demand-side management. The project finalized on 2013.

Until the approval of the royal decree in the 6th of October 2018, the figure of the aggregator was not even a legal possibility. The impact that the implementation of this figure in the Spanish energy market will be discussed in the following chapters.

6.2.2. Electric vehicles

The electric vehicle is a technology that has been trying to enter the transportation market in a competitive way for quite some time now.

The debate of whether it is capable or not of substituting a fuel power car and the many regulatory actions that have been taken in order to at least try to encourage its implementation might have contribute to the reluctance of many possible consumers. Letting some of discussions about autonomy of this type of vehicle it is certainly an interest of this thesis to explore if its implementation could be beneficial to modulate the demand.

It might seem that the substitution of traditional cars by electric vehicles would certainly increase the demand of electricity that the demand side management measures are trying to reduce. However, the reduction of demand is a challenge in terms of efficiency; we should be able to power the same devices but at a lower consumption. In addition, another challenge is to increase the consumption at night so renewable plants do not need to be curtailed and that is where the total implementation is seen as an opportunity. [29]

Assuming that the majority of consumers would charge the electric vehicle during the night; they are already encouraging to do so with the three-period super-off-peak tariff; a technological implementation should be included in the charging stations so the connection of many vehicles at a certain period of time does not provoke another sudden peak in demand.

The solution to properly integrate the charge of the electric vehicle would be to include automatic load management in the stations so the charging could be evenly distributed along the off-peak, increasing the minimum values without provoking new fluctuations in the demand.

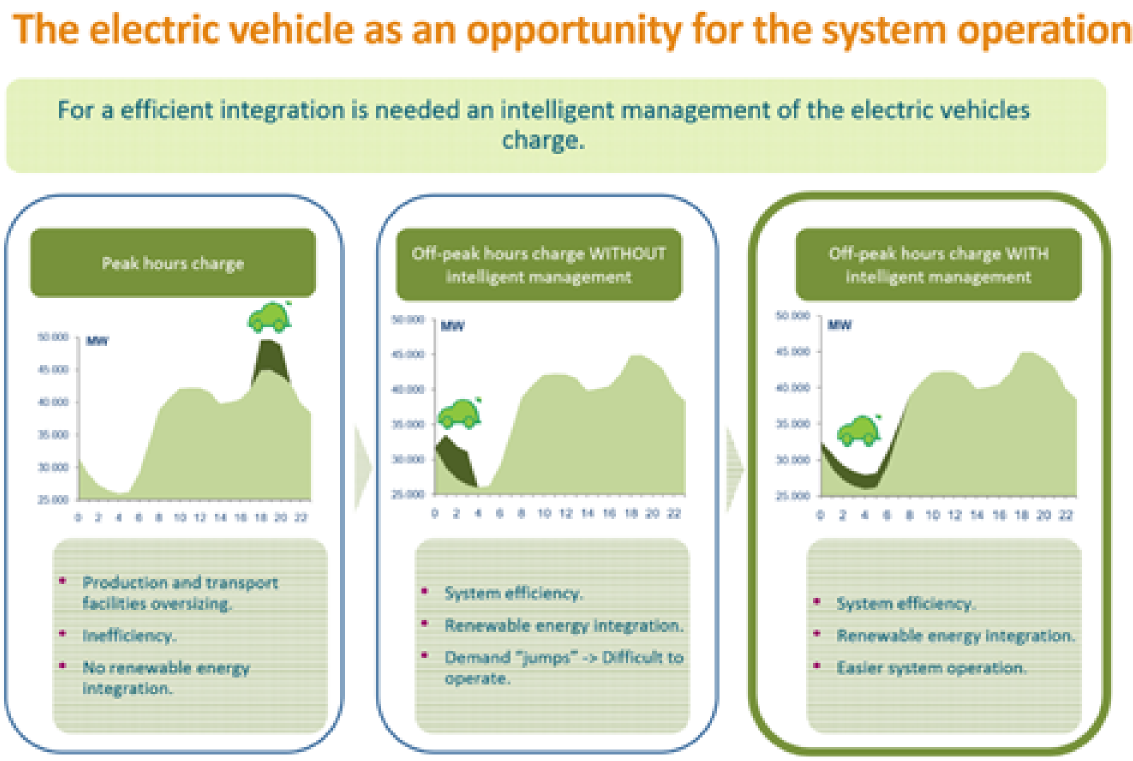


Figure 6.2. - The electric vehicle as an opportunity for the system operation. [8]

Furthermore, although it could be argued that the electric vehicle produces other types of pollutants, it is a certainty that the substitution of traditional cars by this technology will reduce a lot the emissions of carbon dioxide since the transportation only accounts to around 40% of the emissions. [29]

The electric vehicles in Spain are now exempt of paying the registration taxes.

6.2.3. Self-consumption

Self-consumption is defined as the use of instruments in order to produce an amount of energy locally in order to reduce the amount of electricity consumed from the grid. The most common form of self-consumption is performed with PV panels.

Self-consumption is conceived as a possible demand side management measure because the consumers would be able to take an active position regarding not only their consumption of electricity but also their generation. Producing a percentage of the energy that they consume will lower the amount that they get from the grid, helping to reduce the overall consumption especially in the hours of the middle of the day, where there is usually more sun and more demand.

The installation of private small generation units will decrease the overall demand, so the system would need to supply less energy in general and could be able to decrease a little its installed capacity.

We can differentiate into two different types of self-consumption. One of them is conceived for the systems cannot send all the extra energy that they generated to the grid. On the other hand, there are other systems that are designed to send all the extra energy generated to the grid. Especially this last way of self-consumption needs many technical specifications from the grids that needs to be prepare for the flow on electricity in both directions.

In Spain, after the announcement of the change in legislation for self-consumption at the end of 2018 the Government opened a public consultancy about the legislation was to be released. In April 5th, 2019, the royal decree about self-consumption was published. [30]

In this new royal decree, the forms of self-consumption have been identified, giving the consumers the chance to choose self-consumption with and without surplus, and in the case of having surplus it can be compensated or sold. Also, two types of consumers have been defined as individual or collective and in both of them any type of the previously mentioned forms of self-consumption can be applied. In the case of collective consumption all the individuals that conform it should have the same regime. [31]

Also, the owner of the installations does not necessarily have to be the consumer anymore. The bureaucratic red tape has been simplified and the installations up to 15 kW do not need any access permits. [31]

Finally, the royal decree also specifies the measuring equipment that should be installed in each case. For the collective consumers, two equipment measures should be installed, one for consumption and another for the net generation. [31]

7. COMPARISON OF ELECTRIC SYSTEM, DEMAND SIDE MANAGEMENT ACTIONS AND REGULATORY FRAMEWORK

In this chapter a summary of three leading European country's energy system will be done. The aim is to compare the demand side management measures that they are applying and their regulatory frameworks.

The three selected countries are part of the European Union and share the common goals for the Europe horizons.

7.1. Germany

The german territory is divided in four, and four different transmission system operators manage the whole country.

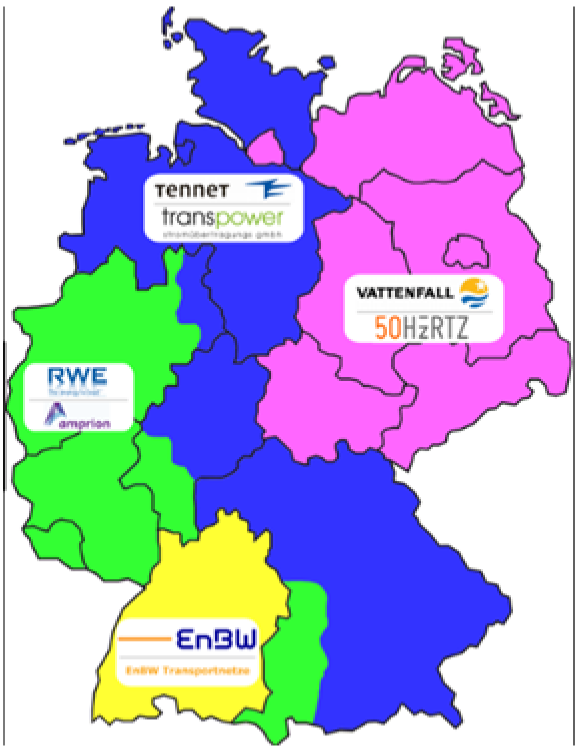


Figure 7.1. - German transmission system operators. [32]

The German government has been pushing for a low carbon economy for quite some time. In Germany, the energy transition to renewables even has a private name, "Energiewende". Some of the pushes to increase the renewable energy share in the generation mix center in the total elimination of nuclear power plants by 2022, which was announce in 2011 backing of a large parliamentary majority. Also, even prior to the commitment of the 2020 Europe goals, Germany approved the Renewable Energy Act in 2000. [33]

Ancillary services

Even though there are four different TSO in Germany, the balancing system used is very similar.

In the territory of 50Hz, the systems accounts with a primary, a secondary and a tertiary reserve. They are available after 15 seconds, 30 seconds and 5 minutes respectively. Regarding the capacity mechanism, the TSO gives permission to pre-qualified suppliers to participate in the bid and so make sure that there is energy available at the reserve. [34]

In the case of Tennet, the ancillary services that manages include compensation of losses of the grid, redispatch, reactive power and balancing reserves.

7.1.1. Interruptible load and tariffs

Interrumpibility model and the type of tariff used in Germany will be identified in this section.

Interrumpibility

The interrumpibility program started in 2013 and it was only intentioned to last three years. However, in 2016 it was approved to last until 2022. Also, after the extension some changes were also implemented. The auctioning for the interrumpibility loads now take place weekly instead of monthly. Furthermore, to make it more accessible the minimum load to bid was 5 MW.

Tariff

The energy tariff scheme used in Germany is highly influenced by the lack of smart meters. The devices have just been started to be installed and so the pricing schemes for the majority of consumers is done with estimated consumption.

The tariffs for consumers must be approved by Supervisory Authority before they are offered. The aim of it is to prevent suppliers to charge consumers excessive high prices while protecting the utilities to have reasonable profits. [35]

7.1.2. New forms of demand side management

Some of the newer actions regarding demand side management in Germany will be identified and discussed.

Aggregation

Aggregation provided by independent parties is very hard due to the regulation barriers. The aggregator should negotiate five different bilateral contracts in order to provide the service. It should agree with the consumer, the consumer's retailer and BRP, the DSO and the TSO, fulfilling all the requirements each of them requires. [36]

A Balance Responsible Party (BRP) is, according to the Commission Regulation EU 2017/2195, "a market participant or its chosen representative responsible for its imbalances". [37]

Self-consumption

As previously stated, the Renewable Energy Act was approved in 2000. It is a law that guarantee feed-in tariffs for the owners of renewable generation units. These feed-in tariffs provided the owners (from home based PV panels to large solar plants) with a price for the power they generated above that one of the market for at least 20 years. In 2016, a reform to this law was perform, setting a new auction system in place of the feed-in tariffs.

According to the federal Ministry of Economic Affairs and Energy in Germany, the amount of self-consumption is growing in Germany and some of the latest systems installed have no subsidies. [38]

Electric vehicle

The german government supported the implementation of the electric vehicle from 2012, where some laws regarding its taxation and incentives were enforced. Later on, some modifications have been performed to these laws.

The initial incentive to exempt all taxed for vehicles that were licensed before December 31, 2015 was extended ten years. The tax exemption can be applied to all the different types of battery electric vehicles, but just to this kind of vehicles. No alternative fuel or hybrid vehicles are suitable. Also, for the electric vehicles licensed from January 1st, 2016 to December 31st, 2020 will be granted with five years of tax exemption. That means essentially that the owners of this type of vehicles are redeemed of paying taxes until 2025. [39]

Also, the government is carrying out the German National Platform for Electric Mobility since 2010, in which it integrates the whole process of the electric vehicle in order to implement it completely into the society. It takes into account the integration of the electric vehicles, plug in hybrids and range extenders. The common factors that these types of vehicles must have is that all of them work by taking power directly from the grid. The platform aims for the electric vehicle market to be self-sustained in the future. [40]

The Federal Government of Germany set the goal of having at least one million electric vehicles in the country by 2020 and try to reach five million by 2025. The integration of this type of mobility will help Germany reduce its greenhouse emissions and achieve the goal set by the European Union. However, in the Progess Report provided by the German National Platform of Electric Mobility it is stated that the ambitious goal of one million cars by 2020 will likely be shifted to 2022. The current rate growth of the market will not make the goal achievable by the initial expectation. In the same way, in the Report is estimated that the number of electric vehicles by 2025 will be around two or three million, far away from the initial target set by the government. [39]

7.2. France

The transmission system operator for the French territory is Rte. Their total installed capacity reaches 130,761 MW, more than 20MW than that of Spain. The data for 2016 and 2017 suggest a decrease in the generation by nuclear and hydro plants and the increase of solar and wind generation. [41]

Ancillary services

In the case of France, the primary and secondary reserves of the ancillary services are managed by the system operator, RTE.

The tertiary reserve or balancing mechanism started to work in France in 2003. Once the primary and secondary reserves have not been able to succeed managing the deviation between production and demand, the transmission system operator informs consumers connected to the grid (industries and households) so they can reduce their consumption. [42]

The participants of the tertiary reserved are chosen by RTE taking into account their technical and financial situations. This method is also used in moments of congestion of the grid.

7.2.1. Interruptible load and tariffs

Interrumpibility model and the type of tariff used in France will be identified in this section.

Interrumpibility

The interrumpibility service was created in 2013. It works in the form of direct contracts between the big consumers of the industry that are the bigger consumers of electricity and Rte, the transmission system operator in France.

Furthermore, in France aggregated loads as a form of demand response is legal in France since 2014. However, at the beginning it was only possible for some strategic sites of transmission networks. In 2016 the service opened to the distribution level, although the rules were not normalized until 2017 were 'full participation' was enabled. [42]

Tafiff

The tariff scheme used in France is a combination between Time of Use (TOU) and Capacity Peak Pricing (CPP) known as "Tempo Tariff". [43]

The Tempo Tariff uses six different rates for pricing depending in the weather and hours of use in a particular day. There are three different types of days, blue, white and red corresponding to low, medium and high prices for electricity. The color of the day is assigned based on the forecast (usually very influenced by the temperature and labor schedule as seen in previous chapters).

In addition to the color code, there is also an off-peck period from 10 pm to 6 am. The consumers are informed about next day's color the previous night through a device installed in their houses.

However, even though it has been proved that the consumers save around 10% of their bill and 90% of them are satisfied with it, less than 20% of the consumers have chosen Tempo to be their tariff. [44]

7.2.2. New forms of demand-side management

Some of the newer actions regarding demand side management in France will be identified and discussed.

Agreggation

Since 2014, in France, the participation of independent aggregators is not only possible but it is also a standard process in which the consumer and the aggregator can directly sign a contract without contacting the BRP. [36]

In the standard contract for aggregation, the volume, compensation, data exchange and governance structure is already settled.

Self-consumption

Before 2016 France did not have a specific regulatory framework for self- consumption. It was possible but only the extra production that was generated could be sold. According to the ministry for the energy transition in France, in 2016 there was an increment in the interest on self-consumption and it gas gather in the Energy Transition for Green Growth Act of 2015, the ordinance and decree extracted from it were ratified at the beginning of 2017. [45]

The government clearly differentiates between individual and collective consumers being the first the ones that produce and consume the energy locally, and the second ones are the ones that form a network, so the energy produce in a certain installation is consumed by more than one consumer and the distributor system operator must be aware and control such a network. For collective self-consumption a contract must be signed with the distribution system operator. Only the individual self-consumption can benefit from tax exemption.

Also, in the current legislation in France, all the self-consumption installations with installed capacity less than 100kW have a specific grid tariff created by the national regulatory authority. Furthermore, consumers with less than 3kW are not responsible for balancing the grid, taking into account that the amount of surplus they will inject into the grid balances with the losses. So, the extra surplus for them is not remunerated. [45]

The self-consumption scheme has now the following characteristics: during up to the first five years of contract a capacity premium is paid based on the power installed of the generation unit and in case the owners decide to fed their surplus generation into the grid they will have the right to access from fed-in-tariffs.

In 2018, the European Union approved the scheme of incentives proposed by France in order to potentiate the self-consumption. The government will designate 200 million euros of the national budget as incentives for projects of up to 500 kW. [46]

Electric vehicle

Each of the regions is allowed to manage their own policies considering tax exemption for the registration fee of electric vehicles. The tax exemption they can offer for the registration fee is either total or 50%. Furthermore, those electric vehicles that emit less than 130g of CO_2 are exempt of paying the registration tax.

Regarding the incentives provided by the government to incentive the usage of electric vehicles, in France the consumers can get 5000 euros when purchasing a car that does not emit more than 60g of CO_2 per kilometer, as it is the case for electric vehicles. Also, as a proof of the government supporting this technology, in 2011 around 50,000 vehicles where distributed to public and private companies by the Environmental Ministry of France. Furthermore, the target of public charging stations installed in France must be of 400,000 by the end of 2020. They accounted for 75,000 public and 900,000 private charging stations by the end of 2015. [29]

According to the data of 2015, France is one of the countries in the European Union where the market for electric vehicles is the most develop. In that year the market share of this type of technology accounted for the 18.56% of the market share.

7.3. The Netherlands

The dutch transmission system operator is TenneT for the high voltage grid. Then, there are twenty-five different regional grid distributors that take the medium and low voltage electricity to the homes. Tennet is also one of the four systems operators of Germany. [47]

Currently, there annual consumption is of around 118.6 TWh. It is also worth remarking that only around 6% of their generation comes from renewable sources. There are no large hydro and solar plants and the country's limited territory and high population is a big constrain for the installation of onshore wind farms.

Ancillary services

The main system used by the transmission system operator is the automatic and manual frequency restoration reserve. The rest of the measures are the same as the ones described in the German chapter since the transmission system operator is the same.

7.3.1. Interruptible load and tariffs

Interrumpibility model and the type of tariff used in Netherlands will be identified in this section.

Interrumpibility

As in the ancillary services, the transmission system operator, Tennet is the same as for Germany so the characteristics for interrumpibility are the same.

Tariff

Regarding the tariffs, in the Netherlands all the retailers have to send the tariffs they offer to the regulator at least four weeks before they are offered in the market. The retailer has to provide the detailed prices for the tariff to the regulators. The regulator has to approve all the tariffs offered in the market to make sure the prices are not excessive, it can limit the tariff if they are too high. [48]

As for the usage of smart meters, they send the information of the consumers to the distributors every two months. The real-time data is provided to the consumer by the retailers. [48]

7.3.2. New forms of demand side management

Some of the newer actions regarding demand side management in Netherlands will be identified and discussed.

Aggregation

In the Netherlands, the aggregation is not allowed as a differentiated service. It is only available to consumers through their retailer. The programs for demand response is totally linked to the electricity price which does not allow competition.

The agents that act like aggregator can only offer services to the Balance Responsible Parties through the balancing, intraday and day ahead markets. So, the imbalances that are mismatches between generation and consumptions should be addressed and settle by the BRP connecting with the TSO.

The only possible way a third party can act as an aggregator is by having a contract with both the consumer's retailer and its BRP and can only provide services to the BRP. This condition supposes a market barrier. If there was more competition in the offers a wider range of consumers participate. [36]

Self-consumption

Self-consumption is allowed in the Netherlands. The net metering system was changed in 2014 and it had a fast market expansion. Also, in the case of extra production the energy produced is then taken by the grid and the "consumer" receives a fed in tariff in exchange. The economic payback time for such an investment is limited to 5-7 years. [49]

The net-metering is only allowed for small consumers, that is systems not larger than 15kW. Considering the average values for consumption and size of PV systems, around a 30% of the electricity consumed in a household annually can be provided by self-consumption. There are around 500,000 residential users of self-consumption in the country.

However, self-consumption is still a bit complicated for the consumers living in apartments due to the prohibition to share PV power in shared buildings.

Furthermore, the government announced that the net-metering system will be replaced by a fed-in tariff by 2020. [50]

Electric vehicle

The Netherlands has one of the largest EV market in the world. This position has been achieved and maintain because of the strong economic incentives and policies that the government has been enforcing in the past years. [51]

The government has announced that by 2030, only emissions free vehicles will be allowed to be registered. The plan to achieve this is the inclusion of subsidies as the 6,000 euros per electric vehicle purchased after 2021. [52]

8. ANALYSIS OF ELECTRIC SYSTEMS AND DEMAND SIDE MANAGEMENT POLICIES

In this chapter we will revise and compare the situation of each of the countries previously discussed to better understand their situation and the demand side management policies and actions that they have already adapt.

8.1. Electric system

We will start the comparison among the different countries by characterizing the type of energy they generate by comparing their fraction of renewables by installed capacity and greenhouse emissions per capita.

2018 DATA	Spain	Germany	France	Netherlands
Total installed capacity [MW]	104975	214840	131940	31976
Renewable installed capacity [MW]	56264	120626	46588	7746
Percentage of renewable installed capacity [%]	54%	56%	35%	24%

Table 8.1. - Total and renewable installed capacity of Spain, Germany, France and the Netherlands. [53]

The integration of renewables is quite high regarding the installed capacity in Germany and Spain with values greater than half. Germany has been applying strong policies to support the energy transition as it was explained in the previous chapter. Spain, on the other hand has many renewable resources in its territory due to its location and also has been providing incentives for these technologies.

France's generation is characterized for the high amount of electricity produce by nuclear power plants and having a significant amount of installed capacity of this technology makes the transition to renewables plants slower. Nuclear power plants cannot be closed immediately, they require a long term plan of various years in case of closing. At the same time, the system has to be careful not to installed much more capacity than the actual needed because it will be costly to manage and not efficient. The lowest value corresponds to Netherlands, however it is already above the 20% overall target proposed by the European Union.

The Netherlands is a small territory with high population density compared to the other countries we are analyzing and so the implementations of renewables that require lot of space is growing at a slower rate. The focus on the next years might be in offshore wind farms.

Now, we will approach the carbon dioxide emissions per person for every country. The reason to take into account the emissions per person is to have a measurement that helps us compare the countries in the same basis since the population of each county varies significantly.

2017 DATA	Spain	Germany	France	Netherlands
tCO2/person	6.2	11	6.9	9

Table 8.2. - CO2 emissions by person in Spain, Germany, France and the Netherlands. [54]

It can be appreciated that the amount of CO_2 released per person might not seem consistent with the values of the previous table regarding renewables. However, the previous table accounts for the installed capacity of renewables, not for the generation made by renewables.

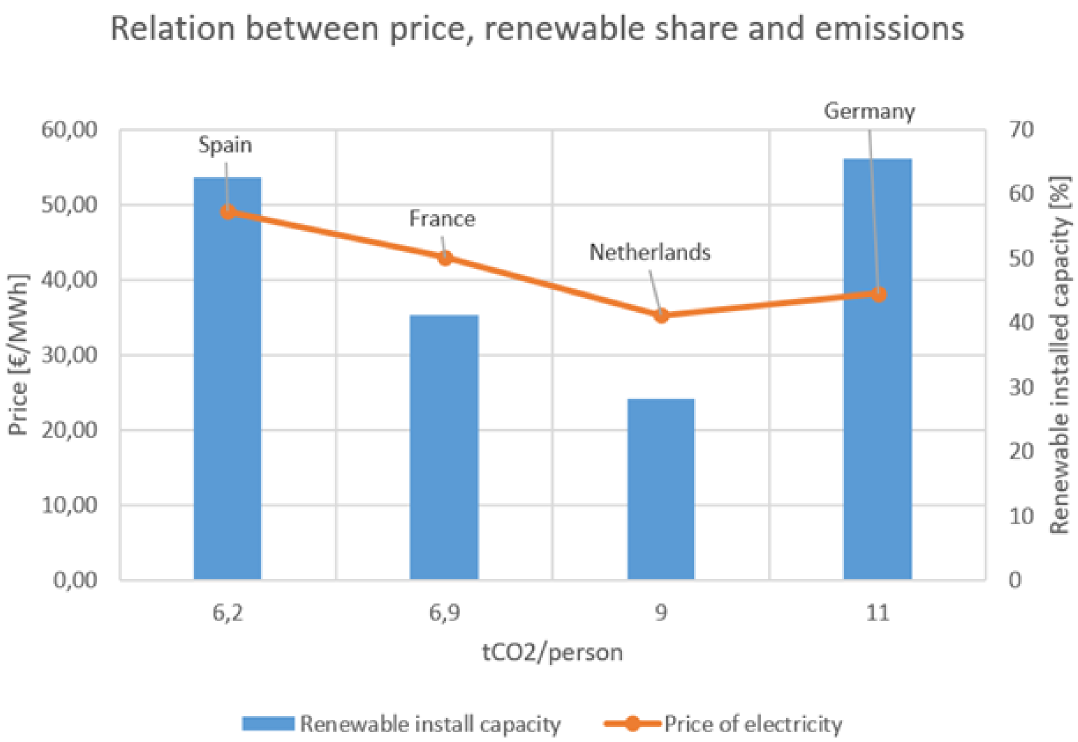
Also, it should be taken into account that there are many other factors that affect the production of CO_2 as factories. Germany that has the highest value for CO_2 emissions among the countries that are being compared is also a very industrialized economy.

We will now continue making a comparison between the average prices of electricity in each of the countries. These are mean values, since as seen in previous chapters each of these countries have different pricing schemes that vary depending on the hour of the day and day of the year. These prices are the average ones of the electricity markets of the countries. The rates for Spain are one of the highest in Europe.

€/MWh	Spain	Germany	France	Netherlands
2018	57.3	44.5	50.2	41.14

Table 8.3. - Prices of electricity market in 2018 in Spain, Germany, France and the Netherlands. [55] [56]

This graph also contrast with the previous ones we have seen in this chapter. Spain has by far the highest price for electricity compared to the other countries. The reason for it might be the access tariffs in which the cost of many past decisions are still being paid. Even though Spain is installing a lot of renewable energy that is cheaper than other conventional sources due to the incentives, the final price for electricity is quite abusive and not competitive compared to other countries in Europe. Putting all the previous information in a graph:



Graph 8.1. - Spain, France, the Netherlands and Germany comparison among price, renewable share of installed capacity and emissions [57]

In the case of price of electricity it can be appreciated that it is higher for the countries with lower emissions. This is not very consistent with the emissions trading system promote by the European Union, by which the more emissions a company produces the higher the taxes it should pay for it. Also, some other factors affect the price as past political decisions and interconnection level. Spain is improving its interconnections but so far the amount of energy that it can exchange is limited.

In the case of renewables it does seem to be a trend among the most renewables installed capacity and the less emissions with Germany as a discordant data. However, as previously mentioned the high amount of installed capacity does not imply a high consumption of energy produced with renewables. And, furthermore Germany is also a very industrialized economy, and so, the greenhouse emissions do not only come from electricity generation.

8.2. Demand side management policies

In this section we will compare the demand side actions and the policies each country is implementing. We will revise the policies mentioned in previous chapters and assign them a numerical value corresponding to the following classification that points out the level of implementation each of the demand side management actions has in every country.

VALUE	MEANING
0	Not yet implemented.
1	Legal but not developed.
2	Supported by policies.
3	Somewhat developed and/or supported.
4	Very developed and supported.

Table 8.4. - Values for analysis [57]

We will use these classifications further in the chapter to characterize each country and compare them.

Interrumpibility

First of all, regarding interrumpibility, it is worth mentioning that France has already allowed aggregated loads to participate as a form of demand response and this action makes the system much more flexible. However, among the other countries that held auctions there is a different among Spain and the others. The auctions that are held weekly might help adjusting the price of the service much more than those held twice a year.

DEMAND SIDE MANAGEMENT POLICY	Spain	Germany	France	Netherland
Interrumpibility	Auctions twice a year. Products of 5 and 90 MW. Security and economic reasons.	Auctions weekly. Minimum bid load is 5 MW.	Aggregated loads as demand response.	Auctions weekly. Minimum bid load is 5 MW.
	4	4	4	4

Table 8.5. - Interrumpibility measure by country [57]

However, it should be notice that the interrumpibility service in Spain is a good incentive for the companies to settle here since the electricity prices are so high compare to these other countries that held them weekly.

Hourly discrimination tariffs

Regarding the hourly discrimination tariff, it is noticeable how Germany has just started implementing smart meters. The lack of them makes it hard to add flexibility through price signals to consumers.

DEMAND SIDE MANAGEMENT POLICY	Spain	Germany	France	Netherland
Hourly discrimination tariffs	Time of used tariff and real time pricing. Not always significant price signals.	Lack of smart meters. Prices approved by Supervisory Authority.	Tempo tariff: time of use tariff and capacity peak pricing.	Real time data is provided. Prices approved by Supervisory Authority.
	3	2	3	3

Table 8.6. - Hourly discrimination tariff by country [57]

On the other hand, it should be remarked that having smart meters is not the only factor affecting it, since the price signals should be sent to the market to incentive consumers to limit their consumption in the peak hours. A contradiction of this can be seen in the previously discussed price comparison between Spain and France.

Aggregation

France is leading regarding aggregation, as is the only country among those compared that allows independent aggregators to participate in the market.

DEMAND SIDE MANAGEMENT POLICY	Spain	Germany	France	Netherland
Aggregation	Not yet implemented.	Many regulation barriers to independent aggregators.	Independent aggregators can offer their service by directly signing with the consumer.	Not independent aggregators. Only possible to contract through retailer.
	0	1	3	1

Table 8.7. - Aggregation policies by country [57]

In Germany and Netherlands the option is possible but it has many regulation barriers that is not a widespread habit along the consumers. In Spain, it is not still implemented, although there used to be an aggregator figure for the management of electric vehicles. The figure of the aggregator for electric vehicles is not implemented anymore.

Self-consumption

Regarding self-consumption, incentives for it seem to be a common policy among the different countries. Spain has just started to do so with the recent elimination of the tax to the sun and further policies might be expected in the following months. In other countries such as France it is even possible to sell the extra production to the grid.

DEMAND SIDE MANAGEMENT POLICY	Spain	Germany	France	Netherland
Self-consumption	Recent impulse through the elimination of the sun tax.	Incentives through fed-in tariffs.	Incentives and possibility to sell the extra generation.	Net metering scheme that will be substitute by fed-in tariffs by 2020.
	1	3	4	3

Table 8.8. - Self-consumption policies by country [57]

Electric vehicle

Finally, regarding the electric vehicle, Netherland is leading as it is one of the biggest markets in the world of electric mobility. Germany and France provide tax exemptions and incentives to those who purchase an electric vehicle. The support of Spain is so far limited to a special three period tariff to potentiate their charge and an exemption to pay registration fee.

DEMAND SIDE MANAGEMENT POLICIES	Spain	Germany	France	Netherland
Electric vehicle	Limited support through special super off-peak tariff.	Tax exemptions for owners.	Incentives and tax exemptions.	Incentives. One of largest EV markets in the world.
	2	3	3	4

Table 8.9. - Electric vehicle policies by country [57]

8.2.1. Final analysis of demand-side management policies in Spain, Germany, France and the Netherlands

After gathering all the information from the analysis of each policy, we obtained:

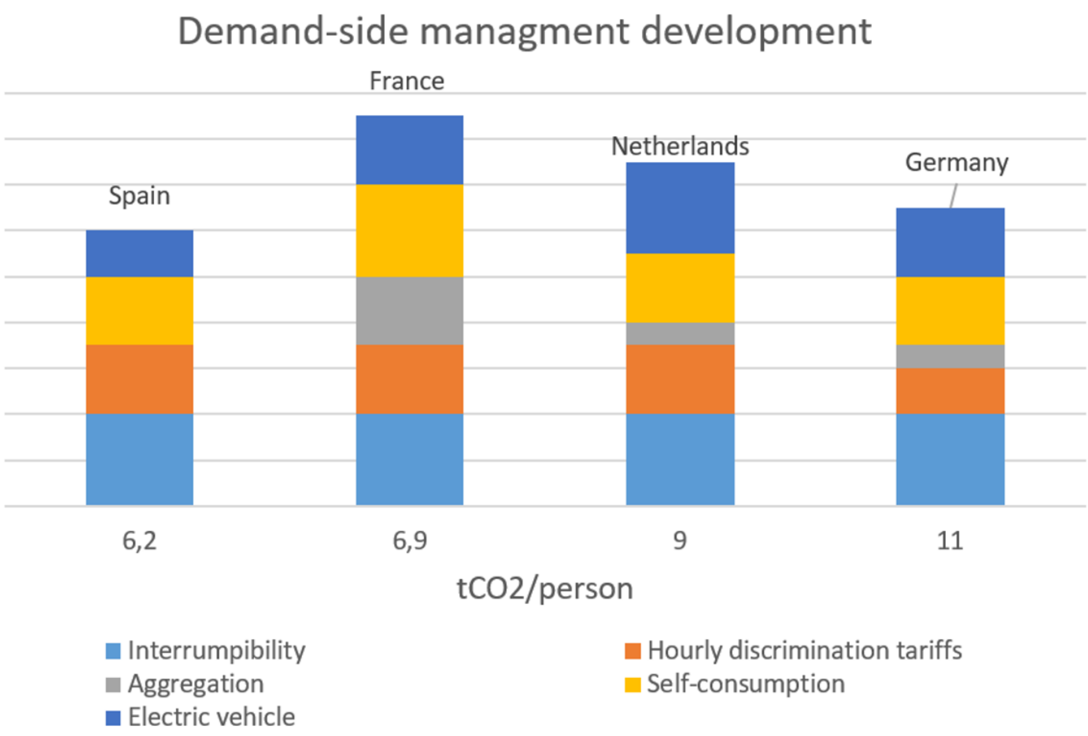
DEMAND SIDE MANAGEMENT POLICIES	Spain	Germany	France	Netherland
Interrumpibility	4	4	4	4
Hourly discrimination tariffs	3	2	3	3
Aggregation	0	1	3	1
Self-consumption	3	3	4	3
Electric vehicle	2	3	3	4
MARK OVER 10	6	6.5	8.5	7.5

Table 8.10. - Demand-side management policies punctuation by country [56]

It can be appreciated in the table that some actions can yet be developed in the different countries. It is also worth remarking that these are just a few of the possible demand side management actions that can be taken so the overall mark is not a complete indicator in the general situation of the country. It is performed with the purpose of comparing the situation of the chosen countries regarding the chosen actions to analyze.

The top results correspond to France and Netherlands, most likely due to their outstanding performance in one of the actions; demand response and the electric mobility respectively. Also, the bottomed performance corresponds to Spain, since couple of actions have just been made legal options and the incentives supporting them are not yet very strong.

Furthermore, we will analyze the impact that these demand side management actions make into the decarbonization which is one of the targets of the thesis. In the following graph we will compare the countries and their policies to their emissions level.



Graph 8.2. - Demand-side management development and emissions by country [57]

It can be appreciated in Graph 13 that it also seems to be a trend such that the lowest emissions correspond to the countries that incentive the most demand-side management policies. However, Spain is now the discordant data, as even though it holds the lowest emission rate of those compared is also the one that has the lowest score regarding incentives of demand side management actions.

As explained before, the reason for Spain to have lower emissions can be due to other factors such as the high share of renewables in the mix. However, if other demand side management actions are taken the emissions could be lower even more.

9. RECOMENDATIONS ABOUT FUTURE ACTIONS OF DEMAND SIDE MANAGEMENT

In this chapter we will gather different recommendations for Spain and a brief comments for the other countries, regarding the possible policies that could be adopt based on the success seen in other countries.

Regarding demand response, after seeing how beneficial the policy has been in France and that the European Union is pushing towards it would be advisable for Spain to start designing a system in which demand response could be included. The inclusion of these action can not completely substitute the interrumpibility service at once, since the adaption should be made slower so the industry has time to adapt to the change.

Furthermore, after the Royal Decree of October 2018 the aggregation of demand has made legal but it has not yet implemented or incentivized by the Government. This could be a great action not only for the system operator but also to the residential consumers that could save a little in their electricity bill, which has significantly increased in the past months.

In the same line, it is very important to provide price signals in the market since the implementation of smart meters and so, the real time pricing and time of use tariff are already a reality that is not always harnessed as we have seen in the previous chapters. No significant differentiation between the peak and the off-peak hours prices does not encourage consumers to shift their consumption to off-peak hours.

Also, regarding the electric vehicle although Spain has tried to incentivize its implementation through the figure of “gestor de cargas” which was a demand aggregator for electric vehicles and the super-off-peak tariff of three periods, the percentage of those is not yet significant. The figure of the “gestor de cargas” is no longer a legal figure in Spain, it is thought that it will not be necessary to impulse the implementation of the electric vehicle. Policies and actions similar than those taken in the Netherlands could be implemented as well as changing the public transport of the cities for the homologous electric options. This latter proposal has already started to be implemented in several Spanish cities.

As an overall recommendation of the European Union, all the countries should increase their level of interconnections with others since the overall trend is to converged to a unified electricity market so the efficiency in the electricity usage will increase and less energy coming from renewable sources will need to be discard due to over production in a certain area.

Finally, as a brief comment on the future of the other countries an impulse and total implementation of the smart meters would be beneficial as real time pricing could be start to be implemented and customers could shift their consumption to off-peak hours.

Also, the Netherlands policies in demand aggregation should be incentivized since their population density is higher than other countries and so the implementation of renewables is harder, aggregation will increase the percentage of use of these type of sources.

10. BUSSINESS OPORTUNITIES

The digitalization of our world is already a reality in most of sectors. However, the utilities sector seems to have been left behind, according to a survey performed to 275 senior executives of the field that took place in January of 2019. [58]

The companies that are leading the market now have to be fast to adapt to both the new technologies and the changing policies in order to keep those positions. New companies might be tented to enter the market by taking advantage of the new possibilities as aggregation of demand and the analysis of data from smart meters.

After the royal decree of October 2018, aggregation will be regularized and self-consumption will boost. These two factors create business opportunities for both, already existing companies in the field and even new entrance companies that would want to focus their activities on demand aggregation or installation, managing and maintenance of self-consumption systems.

Also, many more sensors are thought to be installed so there will be business opportunities for both the companies that design and manufacture them as well for the companies that analyze the data coming from both, the sensors and the smart meters.

10.1. TFG EMPRENDE

As a consequence of the learning from the elaboration of the thesis, an idea to participate in the program “TFG EMPRENDE” from the university Carlos III was developed.

I have been working on the innovation canvas and business model to develop and app that could help consumers understand their electric bill and find out how to save money from consuming at certain periods when the prices are lower. This app also aims to encourage consumers to change their conventional appliances for those that are smart.

The idea is that consumers can understand all the different terms in their electric bill through an easy explanation. Furthermore, if they have a regulated tariff, the prices for the next day will be sent and explained the day before as soon as Red Eléctrica publishes them and so, the consumers can distribute their consumption to save some money in the electric bill.

Moreover, the app will have access to the consumption profile of the consumer though their smart meter data, with this profile the app will be able to calculate how much energy could be saved if a smart appliance of a determined brand was to be installed. The ultimate goal of the app is to improve the energy efficiency, making consumers save in their bill while they provide some flexibility to the grid.

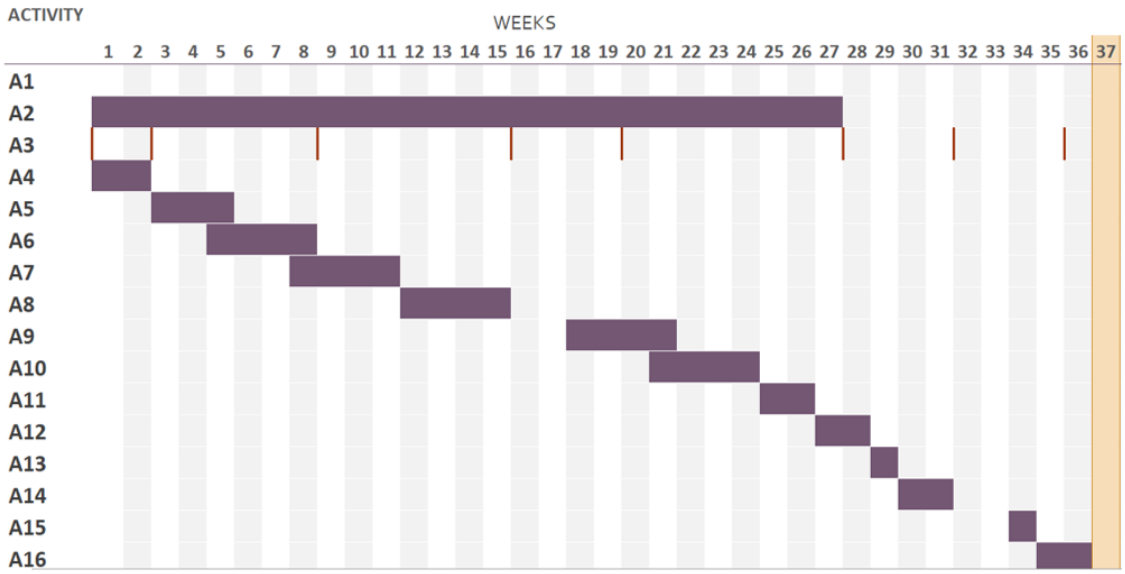
11. TIMELINE OF ACTIVITIES

The development of the thesis has been carried out along 8 months, from October to June. The week 0 is the first week of October when the project was assigned and the first meeting with the tutor took place. The last week considered is the first week of June, the week before the delivery. So, the elaboration of the thesis has been distributed along a total of 36 weeks.

CODE	DESCRIPTION	START	DURATION	END
A1	Basic notions for the elaboration of the thesis	0	1	1
A2	Seach and analysis of information	1	27	28
A3	Meeting with tutor		1	
A4	Write chapter 1	1	2	3
A5	Write chapter 2	3	3	6
A6	Write chapter 3	5	4	9
A7	Write chapter 4	8	4	12
A8	Write chapter 5	12	4	16
A9	Write chapter 6	18	4	22
A10	Write chapter 7	21	4	25
A11	Write chapter 8	25	2	27
A12	Write chapter 9 and 10	27	2	29
A13	Finish chapter 1	29	1	30
A14	Write chapter 13	30	2	32
A15	Write chapters 11 and 12	34	1	35
A16	Edit and format the document into latex	35	2	37

Table 11.1. - Activities description and duration

The elaboration of the project has been distributed along two terms to distribute the workload. Since the schedule and the number of subjects have been different in each of the terms there has not been a continuous schedule for its elaboration nor the same number of hours have been dedicated each week. However, estimating from the routine in both terms and the editing hours reflected by the word document in which it has been written the average of hours dedicated to it per week is to be 12 hours per week giving a total of 432 hours.



Graph 11.1. - Gantt diagram

In the Gantt diagram the distribution of task along time can be appreciated. During the exam's periods of both terms, in January and May there was a reduction on the hours dedicated to the project however documentation and corrections were still being made.

12. BUDGET

In order to compute the budget of the project the labor and the resources costs have been considered. The breakdown can be seen in the following table.

Author	Irene Antón Sierra		
Degree	Energy Engineering		
Department	Electric Engineering		
Project description			
Title	Demand-side management. Key to decarbonization.		
Targets	Study the fuction of demand-side management to achieve decarbonization.		
	Identify policies and actions regarding demand side management of Spain, Germany, France and the Netherlands.		
	Analyze and compare the demand side management policies in Spain, Germany, France and the Netherlands to suggest posible recomendations of future policies.		
Duration	8 months		
Budget breakdown			
Labor cost			
Personnel category	**Total duration (h)**	**Fee (€/h)**	**Total cost (€)**
Junior Engineer	432	14,00	6048,00
Resource and displacements costs			
Type	**Price (€)**	**Amortization cost (€)**	**Total cost (€)**
Personal computer	1200,00	266,67	266,67
Summary			
Concept	**Cost (€)**	**TOTAL (without IVA) (€)**	
Labor	6048,00	**6314,67**	
Resources	266,67		

Table 12.1. - Budget breakdown

To compute the labor cost only the fee of the author fee has been considered although there had been a total of eight meetings with the tutor, whose fee was not computed in the budget.

To compute the resource costs only the amortization of the personal computer has been taken into account. It was computed considering that the lifetime of the computer is three years and for the project it has been used for eight months.

$$Cost_{amortization} = Cost_{total} \cdot \frac{Usage}{Lifetime}$$

It has also been considered that the internet connection and the programs used in the elaboration of the thesis (Word, Excel, Paint, LaTeX) are those provided by the university and so their cost is not reflected in the budget.

Finally, displacements costs to the tutor office has not been considered either, since they have been made with the public travel pass.

13. CONCLUSIONS

In this chapter, both the technical and personal conclusions are presented. A review of the objectives will be done.

13.1. Technical conclusions

First, a revision of the targets established at the beginning of the thesis will be performed to see if those have been achieved. Those targets were to study the impact of demand side management for decarbonization, to identify the state regarding demand side management actions of different countries (Spain, Germany, France and the Netherlands) by studying its policies and to analyze and comparing them to suggest possible recommendations of future policies.

After the elaboration of the thesis it is considered that the objectives have been met. The targets have been solved in the order they are mentioned above and the resolution of the second one has made possible the analysis performed on chapter eight and the recommendations of chapter nine, in which the third objective is met.

Though the meeting of the targets it has been appreciated that the way to reach the European goals is through the increase of energy efficiency and share of renewables decreasing the greenhouse gasses emissions. However, keep installing renewable plants and oversizing the system will not guarantee that the energy production would just come from these type of sources since we will need additional plants or services to cope with the variability of the renewable sources. Furthermore, it will not be energy or economically efficient.

And so, in order to decarbonize the system we need to provide the same service that the conventional sources do: security of supply at all times. We cannot control the generation since the fuel of renewables can barely be predicted. So, the solution to decarbonize the system has to focus on the demand side of the production and demand balance.

The use of demand-side management actions is not completely new as some of them as interrumpibility have been use for quite some time. However, the purpose of using demand side management actions should vary. Interrumpibility has been used just as a last resource when it has been applied for technical reasons.

We have been able to identify the main demand side management actions that will play a key role in the future. Different countries have taken the lead in the implementation of some of them as France with their demand response mechanism and the Netherlands with the electric vehicle.

Spain seems to have stayed behind in some of the proposed actions. However, the legislation has changed regarding aggregation and self-consumption with the royal decree published on October 2018 and that of April 2019. It is expected that new regulations and incentives regarding these actions will be in force in the short future and so Spain will be able to keep on track to meet the targets proposed by the European Union and make a more efficient use of the resources.

Also, many of these actions regarding demand side management are possible thanks to the new technologies and some of the potential usages of the technology have not been used to their potential as the data provided by the smart meters. All these factors provide new business opportunities for companies that are already in the market and for new entrants. The competition for demand side management services will also boost the efficiency of those and so, provide more flexibility to the system.

The aim for the horizon 2050 and the future is to have most of the generation provided by renewables and some little by gas, to cover for the most extreme cases of variability. That will be achieved only by increasing flexibility in the demand through demand side management with a special focus on storage.

13.2. Personal conclusions

Regarding my personal academic formation, elaborating this thesis has been very rewarding and helpful. The thesis has helped me understand all the factors, not only the technical ones that affect the total integration of renewables or the decarbonization. I had been curious about it along the degree and this thesis has complemented my knowledge in this field.

Also, it has provided me with the knowledge on how the electric systems work in Spain and in other countries, as well as what are the tendencies regarding decarbonization settled by the European Union and how each of the countries adapt its policies to meet the targets. This basic knowledge of the sector has been very beneficial for me already during my internship and I think that it will also be in the future jobs. The perspective and understanding of the electric sector has been obtained complements the knowledge regarding the electricity markets provided during the degree.

Furthermore, the elaboration of this thesis has been carried out by searching, readying and analyzing different policies and articles. This has helped me improved my skills on those areas and develop a more critical way of thinking, which has supposed a personal and professional enrichment improving the technical profile obtained along the degree. Also, I have improved my ability of synthesis and wording in a professional manner, and I have improved my writing skills in english. I believed these skills will be crucial in my professional career.

I am sure the knowledge acquired with this thesis will help me orientate better my professional path.

14. BIBLIOGRAPHY

[1] R. M. I. RMI, "energiaysociedad," 26 02 2016. [Online]. Available: http://www. energiaysociedad.es/los-mecanismos-de-flexibilidad-de-la-demanda-podrian-ahorrar-un-10-40-en-la-factura-electrica/. [Accessed Octuber 2018].

[2] E. Comission, "Energy Roadmap 2050," Brussels, 2011.

[3] E. Comission, "eurostat," 24 10 2018. [Online]. Available: https://ec.europa.eu/euro stat/web/products-datasets/-/t2020_33&lang=en. [Accessed November 2018].

[4] M. p. l. T. ecológica, "IDAE," Instituto para la Diversificación y ahorro de la Energía, 11 2011. [Online]. Available: http:// www.idae.es/tecnologias/energias-renovables/plan-de-energias-renovables-2011-2020. [Accessed 11 2018].

[5] Ministerio para la transición ecológico, "miteco," [Online]. Available: https://www .miteco.gob.es/es/cambio-climatico/temas/mitigacion-politicas-y-medidas/objetivos.aspx. [Accessed 11 2018].

[6] European Comission, "Policies, information and services.," [Online]. Available: https://ec.europa.eu/clima/policies/strategies/2020_en. [Accessed December 2018].

[7] IEA, "International Energy Agency," [Online]. Available: https://www.iea.org/ statistics/co2emissions/. [Accessed December 2018].

[8] Red Eléctrica de España, "ree," [Online]. Available: https://www.ree.es/es/red21/efici encia-energetica-y-consumo-inteligente/nuestros-habitos-de-consumo. [Accessed 11 2018].

[9] IDAE, "Plan nacional de acción de eficiencia energética.," [Online]. Available: https://www.idae.es/tecnologias/eficiencia-energetica/plan-nacional-de-accion-de-eficiencia-energetica-2017-2020. [Accessed December 2018].

[10] European Comission - Energy Efficiency, "ec.europa.eu," [Online]. Available: https://ec.europa.eu/energy/en/topics/energy-efficiency. [Accessed 11 2018].

[11] Ministerio para la Transición ecológica. PNIEC, "miteco," [Online]. Available: https://www.miteco.gob.es/es/prensa/ultimas-noticias/el-gobierno-de-espa%C3%B1a-env%C3%ADa-a-la-comisi%C3%B3n-europea-el-borrador-del-plan-nacional-integrado-de-energ%C3%ADa-y-clima-2021-2030/tcm:30-487307. [Accessed 03 2019].

[12] R. A. F. J. J. R. Guirado, "El sector eléctrico," in Tecnología Eléctrica, McGraw-Hill, 2006.

[13] REE, "El sistema eléctrico español. 2017.," 2018.

[14] REE, "Avance del informe del sistema eléctrico español en 2018," 2019.

[15] ICADE, "Expansión. Liberación del sector eléctrico español," 12 2012. [Online]. Available: http://www.expansion.com/2012/01/23/empresas/1327320803.html. [Accessed 12 2018].

[16] CNMC, "Listado de comercializadoras," [Online]. Available: https://sede.cnmc .gob.es/listado/censo/2. [Accessed 12 2018].

[17] Expansión, "Expansión," 2018. [Online]. Available: https://sede.cnmc.gob.es/ listado/censo/2. [Accessed 12 2019].

[18] datosmacro, "PIB de España - Producto Interior Bruto," [Online]. Available: https://datosmacro.expansion.com/pib/espana. [Accessed March 2019].

[19] REE, [Online]. Available: https://www.ree.es/es. [Accessed 2018].

[20] REE, "Ancillary Services. Preliminary report 2017.," [Online]. Available: https://www.ree.es/sites/default/files/11_PUBLICACIONES/Documentos/ancillary-services-preliminary-2017.pdf. [Accessed February 2019].

[21] OMIE, "omel," 2018. [Online]. Available:

http://www.omel.es/en/home/markets-and-products/electricity-market/our-electricity-markets. [Accessed 12 2018].

[22] Energía y sociedad, "Energia y sociedad. El mercado minorista," 2018. [Online]. Available: http://www.energiaysociedad.es/manenergia/5-1-el-mercado-minorista-de-energia-electrica/. [Accessed 12 2018].

[23] IEEE Terminology Task Force, "Vol. PAS-104 No. 9," in "Glossary of Terms Related to Load Management", Trans. Power Apparatus and Systems, 1985, pp. pp. 2381-2392.

[24] US department of energy, "SMARTGRID.GOV," Time based rate programs, [Online]. Available: https://www.smartgrid.gov/recovery_act/time_based_rate_programs. html.[Accessed April 2019].

[25] D. Frankel and A. Wagner, "McKinsey. Battery storage: The next disruptive technology in the power sector," 06 2017. [Online]. Available: https://www.mckinsey.com /business-functions/sustainability/our-insights/battery-storage-the-next-disruptive-technology-in-the-power-sector. [Accessed January 2019].

[26] Ministerio de economía, "BOE-A-2001-20850," 2011.

[27] Easy storage, "Cortes-Muela: the Largest Pumped-Hydro Storage Plant in Europe," [Online]. Available: http://ease-storage.eu/la-muela-ii-is-the-largest-pumped-hydroelectric-storage-plant-in-europe/. [Accessed 01 2019].

[28] BOE, "Boletín oficial del Estado.," Gobierno de España., 06 October 2018. [Online]. Available: https://www.boe.es/boe/dias/2018/10/06/. [Accessed December 2018].

[29] J. M. Cansino, A. Sánchez-Braza and T. Sanz-Diaz, "Policy Instruments to promote electro-mobility in the EU28: a comprehensive reviw," Sustainability. MDPI, 2018.

[30] Ministerio para la transición ecológica. , "Propuesta de real decreto por el que se regulan las consiciones administrativas, técnicas y económicas del autoconsumo.," [Online]. Available: https://www.miteco.gob.es/es/ministerio/servicios/participacion-publica/ Real-Decreto-de-Autoconsumo.aspx. [Accessed February 2019].

[31] BOE, "Boletín oficial del estado," MINISTERIO PARA LA TRANSICIÓN ECOLÓGICA, 06 04 2019. [Online]. Available: https://www.boe.es/boe/dias/2019/04/06/pdfs/BOE-A-2019-5089.pdf. [Accessed May 2019].

[32] Renewable energy world, [Online]. Available: https://www.renewableenergy world.com/articles/print/volume-17/issue-3/solar-energy/regarding-the-grid-and- solar-pv-us-utilities-are-asking-what-would-germany-do.html. [Accessed Aprill 2019].

[33] Agora, "Agora Energywende," [Online]. Available: https://www.agora-energie wende.de/en/service/recent-electricity-data/chart/power_generation/06.03.2018/06.03.2019/. [Accessed April 2019].

[34] 50hertz, "Market processes and market roles.," [Online]. Available: https://www. 50hertz.com/en/Market/Marketroles. [Accessed April 2019].

[35] Joachim Rudo, "Energy Law," [Online]. Available: www.energylaw.de. [Accessed April 2019].

[36] P. Bertoldi, P. Zancanella and B. Boza-Kiss, "Demand Response status in EU Member States," European comission. JRC science for policy report, 2016.

[37] Gtowacki Law Firm, "Emissions-EUETS," Balance Responsible Parties , [Online]. Available: https://www.emissions-euets.com/-balance-responsible-parties-brp. [Accessed May 2019].

[38] J. Wettengel, "Clean energy wire. Journalisim for energy transition," A brief timeline of Germanys Energiewende, April 2017. [Online]. Available: https://www.clean energywire.org/factsheets/very-brief-timeline-germanys-energiewende. [Accessed March 2019].

[39] "German National Platform for Electric Mobility".

[40] IEA, "Hybrid and electric vehicle. Technology collaboration programme," [Online]. Available: http://www.ieahev.org/by-country/germany-policy-and-legislation/. [Accessed April 2019].

[41] RTE, "Annual electricity report," [Online]. Available: https://www.rte-france.com/en/article/annual-electricity-reports. [Accessed March 2019].

[42] RTE, "RTE France. Balancing mechanism," [Online]. Available: https://www.rte-france.com/en/article/balancing-mechanism.

[43] O. Youssef, J. Manuel, M. Espeche, T. Sisinni and Messervey, "Residential Electricity Tariffs in Europe: Current Situation, Evolution and Impact on Residential Flexibility Markets," 2017.

[44] iea dsm , "Energy efficiency," [Online]. Available: http://www.ieadsm.org/article /tempo-electricity-traiff/. [Accessed April 2019].

[45] L. Oriol, "Self-consumption framework in France," 2018.

[46] E. Bellini, "EU apprves France's new scheme for self-consumption," October 2018. [Online]. Available: https://www.pv-magazine.com/2018/10/23/eu-approves-frances-new-scheme-for-self-consumption/. [Accessed March 2019].

[47] TenneT, "Tennet. Taking power further," [Online]. Available: https://www.tennet. eu/our-key-tasks/energy-industry/grid-operators/. [Accessed April 2019].

[48] A. J.Ros, T. Brown, N. Lessem, S. Hesmondhalgh, J. D. Reitzes and H. Fujita, "International Experiences in Retail Electricity Markets," June 2018. [Online]. Available: https://www.accc.gov.au/system/files/Appendix%2011%20-%20The%20Brattle%20Group %20-%20International%20Experiences%20in%20Retail %20El....pdf. [Accessed May 2019].

[49] G. Masson, J. I. Briano and M. J. Baez, "Review and analysis of PV. Self-

consumption policies.," Photovoltaix power systems programme, 2016.

[50] P. Bancourt, "REPORT ON PVP4GRID; CONCEPTS AND BARRIERS," European Renewable Energies Federation (EREF): , Brussels, 2018.

[51] C. Morris, "8 European countries and their EV policies," EVANNEX, 2018. [Online]. Available: https://cleantechnica.com/2018/11/04/8-european-countries-their-ev-policies/. [Accessed May 2019].

[52] C. Randall, "electrive," Netherlands develop new electric vehicle incentives, November 2018. [Online]. Available: https://www.electrive.com/2018/11/30/netherlands-develop-new-ev-purchase-incentives/. [Accessed May 2019].

[53] entsoe, "Transparency platform," Installed capacity, [Online]. Available: https://transparency.entsoe.eu/transmission-domain/r2/dayAheadPrices/show. [Accessed May 2019].

[54] Global Carbon Atlas, "CO2 emissions," [Online]. Available: http://www.globalcarbonatlas.org/en/CO2-emissions . [Accessed May 2019].

[55] Asociación de Empresas con Gran Consumo de Energía, "AEGE," Barómetro energético en España, [Online]. Available: http://www.aege.es/barometro-energetico-espana/. [Accessed May 2019].

[56] EPEX, "EPEX Netherlands," Spot prices , [Online]. Available: https://www.apxgroup.com/trading-clearing/apx-power-nl/. [Accessed May 2019].

[57] "Own source," [Online].

[58] "The Future of Utilities Report 2019," UK, 2019.

[59] eurostat. Statistics Explained, "Greenhouse gas emissions statistics - emission inventories," June 2018. [Online]. Available: https://ec.europa.eu/eurostat/statistics-explained/index.php/Greenhouse_gas_emission_statistics. [Accessed December 2018].

[60] eurostat. Statistics Explained., "Renewable energy statistics," [Online]. Available: https://ec.europa.eu/eurostat/statistics-explained/index.php/Renewable_energy_statistics. [Accessed December 2018].

[61] eurostat. Statistics Explained, "Primary energy consumption," [Online]. Available: https://ec.europa.eu/eurostat/web/products-datasets/-/t2020_33&lang=en. [Accessed December 2018].

[62] esios, "Mapa de consumidores con contador inteligente telegestionado por comunidad autonoma.," [Online]. Available: https://www.esios.ree.es/es/mapas-de-interes/mapa-de-consumidores-domesticos-con-contador-inteligente-telegestionado-por-comunidad-autonoma. [Accessed 2018].